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ASSESSMENT OF REFUELING HOSE VISIBILITY

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14. ABSTRACT A quantitative assessment of aerial refueling hose visibility was conducted by the 711 HPW/RHCV in response to a request from the Aerial Refueling Systems Advisory Group (ARSAG) and the Naval Air Systems Command, Fuel Containment and Aerial Refueling Systems (NAWCAD). The objective of this effort was to determine the visibility (contrast) of six different refueling hoses varying by color and markings including one never-used new hose and five with obvious signs of usage. The primary variable measured was the contrast between the markings and the hose under several illumination and viewing geometries as well as assessments made for other spectral band sensors. Additional subjective assessments were made of images captured using NVG, SWIR and LWIR sensors of each of the hoses samples. Results demonstrated that contrast between the refueling hose samples and markings are dependent on the viewing and illumination geometry, with the new, 'unused' hose sample markings at a much higher contrast ratio than the other five used samples. A discussion regarding the implications of these findings to other real-world conditions causing contrast degradation during aerial refueling is presented. Recommendations for further evaluations to assist in the determination of standards for minimum allowable contrast of refueling hose markings before cleaning or replacement are discussed.

15. SUBJECT TERMS
Aerial refueling hose, visibility, contrast, illumination, viewing geometries, spectral band, NVG, SWIR, LWIR, standards

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1 SUMMARY

This effort was initiated by the Aerial Refueling Systems Advisory Group (ARSAG) and the Naval Air Systems Command, Fuel Containment and Aerial Refueling Systems (NAWCAD) with the objective of obtaining a quantitative assessment of aerial refueling hose visibility conducted by the Air Force Research Laboratory's Battlespace Visualization Branch (711 HPW/RHCV). 711 HPW/RHCV had previously conducted limited refueling hose evaluations for ARSAG and provided summary letter reports of the results (Appendices E and F).

The primary objective of this evaluation was to determine the visibility (contrast) of the refueling hose markings for both white hoses with black markings and black hoses with white markings. The US Navy and ARSAG provided 6 hose samples for 711 HPW/RHCV to assess. These hose samples included a new hose sample as well as used hose samples that showed obvious signs of use.

The primary variable that relates to the visibility of the refueling hose markings was assumed to be the contrast between the markings and the hose. This contrast was measured (as a contrast ratio) for all six hoses under several illumination and viewing geometries. Measurements were made using a photometer, which simulates the human eye in its sensitivity to light. Assessments for other spectral band sensors than might be used by aircrew were conducted. Assessment for night vision goggles (NVGs), short-wave infrared (SWIR) sensors, and long wavelength infrared (LWIR - thermal) sensors were conducted subjectively by evaluating images of the hose samples captured with each of these sensors.

Results of the visible spectral band measurements clearly demonstrated that the new hose sample marking had a much higher contrast ratio than the used hose samples (contrast ratio of 19.6 versus 1.2 to 15.3 for the other hoses), as one might expect. Also, all hose samples demonstrated significant loss in contrast for illumination geometries in which the illuminating source was in an equal and opposite direction from the viewing angle due to specular (mirror-like) reflection from the surface of the hose. The effect was more pronounced as the viewing angle was closer to the axis of the hose, much like the viewing angle a pilot has of the refueling hose. Although the new hose sample showed superior contrast for this viewing geometry, even its contrast was significantly affected by the shallower viewing angle dropping from a contrast ratio of 19 down to a 7.8 as the viewing angle changed from 60 degrees to 30 degrees (angle between viewing direction and the hose axis). The older hoses showed a more rapid drop in contrast ratio perhaps indicating their surfaces had been worn smoother causing a larger specular reflection effect.

The subjective photographic results indicate visible and NVG wavelength contrast appear to be similar to each other with SWIR slightly worse than the visible spectrum (lower contrast) and LWIR substantially worse (almost no contrast) as the dark and light parts of the hose had very little temperature difference, which is what the LWIR sensor is sensitive to.

In addition to the physical evaluation of the hose samples, brief theoretical discussions of other effects that can cause substantial loss in contrast available to the pilot are presented. These include the effects of windscreen haze; reflections in the windscreen of the aircraft glare shield,

and ambient lighting conditions such as bright backlighting from clouds or uneven hose illumination by sunlight directions off to the sides.

Appendices A, B, C, D, E, and F provide the background documents that were used to guide this assessment.

2 INTRODUCTION

The primary guiding statement for the refueling hose visibility evaluation described in this report stems from section 3.1 of Appendix A (Aerial Refueling Hose Color and Markings Evaluation Criteria):

> *Acceptable minimum / maximum hose color to marking contrast range under a variety of lighting conditions. This should permit the pilots to detect hose movement and position from the tanker hose / drogue exit. This distance (pilot eye to drogue exit) may range from approximately 10‘ to 90‘ depending on the type of tanker drogue hose reel retracting / storage system.*

This statement makes it clear that the primary objective of this effort is to determine how well a pilot can see the markings on the refueling hose in order for the pilot to make judgments of hose movement and position. As suggested in the excerpt above, one of the key factors in determining the visibility of hose markings is the contrast between the hose markings and the rest of the hose under various lighting conditions. A second factor that can be discussed, which was not experimentally evaluated for this report, is the apparent angular size of the markings as viewed by the pilot (which may also impact how easy it is to see the hose markings). Note that this visibility objective is different than determining the visibility of the hose (marked or unmarked sections) against a variety of background scenes.

2.1 Contrast as the Primary Metric for Visibility Assessment

There are at least three widely used equations to calculate contrast. Based on the guiding discussions for this effort, *contrast ratio* was the primary parameter calculated and graphed to assess visibility. Contrast ratio is the ratio of the luminance of the lighter part of the object to the luminance of the darker part of the object, which yields a number than can range from a minimum of 1.0 (no contrast) to a maximum of infinity. In equation form:

$$C_r = L_{max}/L_{min} \qquad (1)$$

where: C_r = contrast ratio
L_{max} = luminance of the lighter part of the object (hose)
L_{min} = luminance of the darker part of the object (hose)

Another frequently used formula for contrast is *modulation contrast,* also known as Michelson contrast. The value of this quantity ranges from 0 to 1 but is often converted to "percent" as in "50% contrast," which is accomplished by multiplying the modulation contrast by 100. So, for example, a modulation contrast of 0.5 would be 50% contrast. The equation for modulation contrast is:

$$C_m = (L_{max} - L_{min})/(L_{max} + L_{min}) \quad (2)$$

where: C_m = modulation contrast (multiply by 100 to get percent)
L_{max} = luminance of the lighter part of the object (hose)
L_{min} = luminance of the darker part of the object (hose)

Although contrast ratio will be used extensively in this report, it may also be worthwhile to look at the results in modulation contrast terms. The equations below allow one to directly convert from contrast ratio to modulation contrast and vice-versa, if desired:

$$C_m = (C_r - 1)/(C_r + 1) \quad (3)$$

$$C_r = (C_m + 1)/(C_m - 1) \quad (4)$$

where the variables are defined the same as in equations 1 and 2.

2.2 Angular Size of Hose: Effects of Viewing Distance

One important aspect of determining the visibility of an object in real world scenarios is the projected size of the object compared to the distance from which it is viewed. The projected size refers to the fact that, other than a sphere, the apparent (projected) size of an object depends on the angle of the object's dimensions (surfaces) with respect to the view angle. For example, in the case of a flat piece of paper (x inches high by y inches wide) the paper might be extremely visible if viewed perpendicular to its surface. However, if it is viewed at a slant angle to its surface then it will appear to be smaller due to foreshortening. In the extreme case, if one were to view the paper edge on (a zero degree angle with respect to the plane of the surface of the paper) then the paper may well be essentially invisible. The same geometry considerations must be taken into account when determining the visibility of a refueling hose.

In the case of the refueling hose, one can consider it a flexible cylinder with the view angle (pilot's view) making some small angle with respect to the axis of the cylinder. Figure 1 is a photograph from the pilot's eye position looking toward the refueling tanker with the hose clearly getting "smaller" as one looks closer to the tanker aircraft. Note that this foreshortening only occurs for object dimensions that are not perpendicular to the line of sight. However, the apparent size of the object is still smaller the farther away it is. In order to determine the contrast requirements for visibility it is necessary to determine the angular size of an object. For relatively small objects (those that subtend less than 1 degree) the angular subtense of the object in milliradians can be calculated using the approximation equation 5:

$$\alpha = 1000^* (s/D) \quad (5)$$

where: α = Alpha, angular subtense of object in milliradians
s = projected size of object
D = distance from viewer to object (in same units as "s")

In order to get some estimate of the worst case refueling hose apparent size one can simply use the diameter of the smallest hose viewed from the maximum distance in order to bound the problem. The smallest hose measured was hose sample number 2, which had an outside diameter of 2.0 inches. From the information contained in Appendix A, the maximum distance is about 90 feet. Substituting these numbers into equation 5 one obtains an angular size of about 1.85 milliradians, which is about 6.4 arc minutes. We will use this number later in section 2.4 to determine how "visible" the hose markings are for the hose samples.

Figure 1. Refueling Hose Markings Appear Smaller The Farther Away They Are

2.3 Lighting and Viewing Angle Effects on Hose Marking Visibility

Lighting can be a significant factor in the visibility of a refueling hose. Visibility to the pilot is affected not only by the amount of light but also by the direction and angle from which the light illuminates the hose. Notice in Figure 1 the white parts of the hose are being illuminated from a light source (the sun) as the right side of the hose is easily seen but the left side is in shadow with the result that the hose is not equally visible from all directions. This can have an interactive effect with the previously discussed variable (angular subtense) in that only part of the hose diameter might be visible if the lighting conditions are extreme and directional from the sides. In fact, the lighter parts of the hose may appear to be only half (or even less) than the diameter they actually are.

2.4 How Much Contrast Is Needed For Good Visibility?

In general, the more contrast the easier it is to see the refueling hose markings. However, from the previous two sections we see that the hose visibility depends on both the contrast of the markings and the apparent (angular) size. In order to set a lower absolute limit on contrast one can turn to the literature on contrast thresholds for non-periodic objects, such as the Blackwell disc data. Figure 2 is a graph extracted from Farrell and Booth (1984)[1] reporting on experiments done with detection of circular discs of different sizes against a uniform background for a short duration (0.3 sec) exposure. This is obviously not exactly the same as looking for the markings on a refueling hose, but it provides something of an absolute minimum contrast needed.

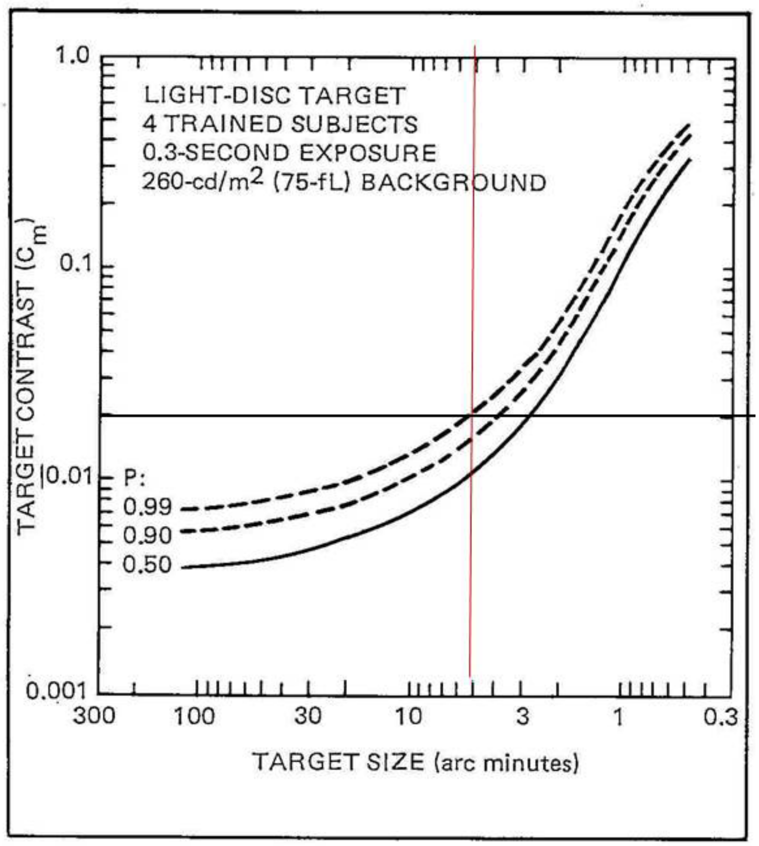


Figure 2. Target Contrast Required to Detect a Circular Disc Against a Uniform Background With A 0.3 Second Exposure. From Farrell and Booth (1984), P3.1-17

The upper dotted line in Figure 2 corresponds to a 99% probability of detecting the circular disc and the vertical line starting at the bottom at about 5 arc minutes intersects the upper dotted line at about 0.02 *modulation* contrast. Using equation 5 one can convert this to contrast ratio obtaining a value of about 1.04. The 5 arc minutes is less than the 6.4 arc minutes calculated in section 2.3 as the approximate minimum size hose marking (depending on lighting) that would be viewed by the pilot and is therefore a convenient, size value to look at. Bottom line: in theory, one should be able to see hose markings at the extreme distance from the pilot (90 feet) if the contrast ratio is only 1.04. From a practical standpoint one does not want to encounter a visibility condition anywhere near threshold for viewing a critical element such as the markings on the refueling hose.

The Human Engineering Guide to Equipment Design suggests the minimum symbol contrast displayed on a display subject to ambient light (which reduces the contrast) should be a contrast ratio of 1.2 to 1. Also, both the Joint Helmet Mounted Cuing System (JHMCS) helmet display and the F-35 Gen 5 helmet mounted displays have a requirement of a minimum contrast ratio of 1.2 to 1 for viewing symbology against high luminance backgrounds. Based on this information it is reasonable to select a contrast ratio of 1.2 to 1 as the desired absolute minimum contrast ratio for refueling hose markings under any viewing conditions including viewing through different sensors such as night vision goggles. A higher contrast ratio is highly desirable to assure extremely easy detection of markings under field lighting/viewing conditions.

Although the pictures in Figure 3 are somewhat small, they demonstrate the shallow angle of view that the pilot has when viewing the far end of the hose and the difficulty in seeing the hose markings at the extreme distance.

Figure 3. Pictures of Refueling Hoses from Pilot's Viewpoint Demonstrating the Difficulty of Seeing the Hose Markings at the Far End of the Hoses

2.5 Relation between Contrast Ratio, Reflectance Coefficients, and Specular Reflections

One of the key factors in determining visibility of an object (in this case the "object" is the marking on the refueling hose) and the background or adjacent surface (in this case the rest of the refueling hose) is the contrast ratio between the two. As noted above, the definition of contrast ratio is the ratio of the luminances (also commonly called "brightness," which is incorrect but often used) of the two surfaces (markings and rest of hose). The luminance of a non-emitting surface depends on four things: 1) the amount of illumination falling on the surface, 2) the direction of the illumination source (azimuth and elevation angles), 3) the view direction toward the surface (azimuth and elevation), and 4) the reflectance coefficient of the surface for those specific illumination/viewing conditions. If the two surfaces for which contrast is to be calculated are illuminated identically and the view angle toward the two surfaces are essentially the same, then the contrast between the two surfaces depends entirely on the reflectance coefficients of the two surfaces and can be calculated from the reflectance coefficients. This is a very helpful and time-saving fact. However, in order to fully characterize the possible contrasts that one may encounter when viewing the refueling hose markings from different directions and illuminated from different directions one would have to generate what is known as a bidirectional (azimuth and elevation) reflectance distribution function or BRDF. This is extremely time-consuming and impractical. In order to get a reasonable assessment of the visibility of the refueling hose markings, the reflectance coefficients of the light and dark surfaces of each sample hose were measured for a small and operationally relevant subset of all the possible illumination/viewing angle combinations.

In general, most surfaces scatter light non-uniformly when illuminated from a single direction. A surface that does scatter light uniformly is referred to as a Lambertian surface and is commonly known as a "flat" (non-glare or no sheen) surface. If a surface has a "sheen" to it (glossy, semi-glossy, etc.) then it will have something of a specular or "mirror-like" nature to it.

What this means is that if one is viewing the hose marking from an equal and opposite angle as the illumination source then one might get a glare effect. This glare or specular reflection effect can reduce the contrast between the markings and the hose. This is one of two possible "worst case" scenarios for viewing the refueling hose and is why the measurements presented in Section 3.2 of this report were collected. These measurements of the reflectance coefficients were done using a view (measurement) angle equal and opposite to the illumination angle to capture this "worst case" situation.

For comparison, the reflectance coefficients of the hose samples were also measured using a selection of non-specular reflection geometries and are presented in section 3.1.

2.6 Human Vision Adaptation State (Background Luminance Effects)

A second "worst case" scenario has to do with the ambient lighting conditions and the fact that the human visual system adapts to the ambient light level of the overall scene. This is a difficult situation to quantify but it should at least be mentioned. An example of this situation would be a sun position relatively near the horizon off to one side and somewhat behind the aircraft being refueled such that the sun is side-lighting the hose (making only about half of it "brightly" illuminated) with brightly-lit white clouds serving as a background to the hose from the pilot's viewpoint. This would mean the hose is somewhat dimly lit because of the shallow angle between the hose surface and the direction of sun illumination, only about half the hose is illuminated (from the side); but the background clouds are brightly lit because they are more or less perpendicular to the sun illumination angle. This situation is akin to trying to photograph an object that has a bright background - the contrast within the object (in our case, the hose and markings) appears dark compared to the bright background making it difficult to see details (the hose markings) within the object. Figure 4 attempts to demonstrate this effect, although part of the reason the markings are not visible is the distance as opposed to the brightly-lit background.

Figure 4. Back-Lit Aerial Refueling Hose Makes It Difficult To See the Markings (As Well As, Of Course, the Distance from Photographer to Hose)

2.7 Spectral Band Effects

Daytime aerial refueling is conducted with the unaided eye as the sensor that needs to be able to detect the hose markings. However, night refueling may involve night vision goggles (NVGs) or some other vision device that allows the pilot to view the hose markings. Materials that may have good contrast in the visible light wavelengths (nominally 400nm to 700nm) may not have good contrast in other spectral bands (such as 600nm to 930nm - the NVG wavelengths). Originally, the test plan was to conduct spectral scans of the hose samples to capture contrast effects in the NVG wavelengths and the short-wave infra-red (SWIR) wavelengths (nominally 0.9 to 1.7 microns). However, the spectral scanning radiometer was uncalibrated for the SWIR wavelengths and, from photographic images taken through NVGs, it was decided that there was little to be gained from the multiple spectral scans that would have been necessary to collect the data to populate Table 1 of Appendix C (the Test Plan). The photographs through NVGs indicate the materials used in the hoses tested treat the NVG wavelengths similar to the visible wavelengths (see Figures 27 and 28).

A search of the internet resulted in the discovery of the following May 2012 article and photograph of aerial refueling using night vision goggles. Figure 5 is the NVG photograph from the article. The full article and reference can be found in Appendix D.

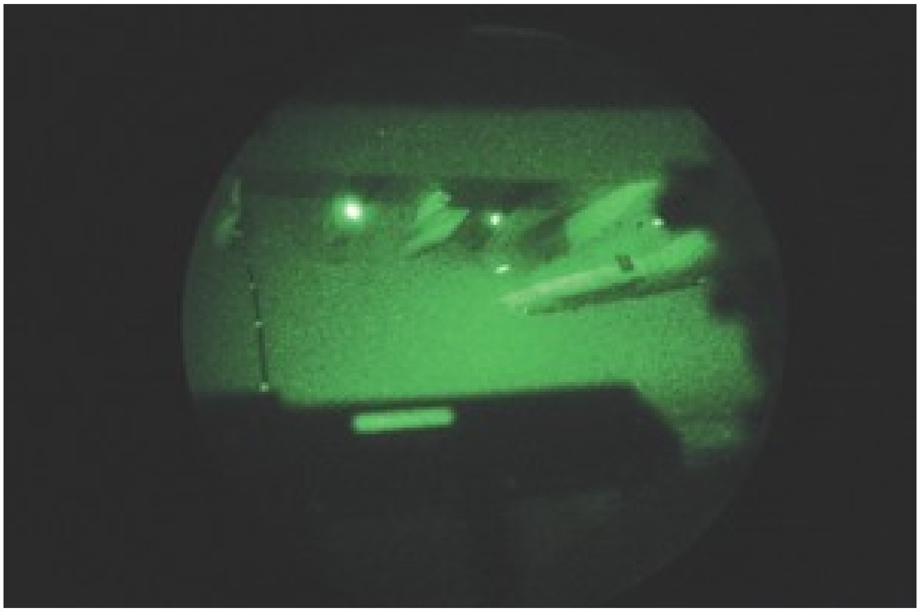


Figure 5. Aerial Refueling at Night Using NVGs from ROTOVUE On-Line Publication, 23 May 2012. VMM-162 Refuels Under Cover of Darkness, By Lance Cpl. Kyle N Runnels[2]

It is evident from the picture included with the article that the markings on the hose are reasonably visible through the NVGs. The markings may be composed of retro-reflective, white tape but whatever they are made of it is evident they are easily visible through the NVGs (although more difficult to see as the markings are closer to the tanker end of the hose).

Images using various sensors (NVG, SWIR, and long-wave infra-red or LWIR) can provide at least a qualitative assessment of the level of contrast to expect for the different spectral bands represented by these sensors. Images of the hose samples produced using these sensors are in Section 3.1.3 for qualitative visual assessment of contrast.

2.8 Effects of Aircraft Windscreen and Head-Up Display (HUD) Combiner Glass

Modern military aircraft may have glass or plastic windscreens or canopies, which can become somewhat scratched or dirty over time and thereby reduce the apparent contrast of objects viewed by the pilot when looking through the windscreen. In a perfect world, a transparency such as an aircraft windscreen would not impact the contrast of objects viewed through the windscreen no matter what the transmission coefficient of the windscreen. However, if there is a veiling light introduced by the presence of the aircraft windscreen then there is an interaction between the windscreen transmission coefficient, the amount of veiling light, and the apparent (reduced) contrast of the object viewed through the windscreen. The purpose of this section is to present a theoretical (but observed in the field) structure to allow one to understand the potential impact of these windscreen effects on refueling hose visibility under real field conditions. Figure 6 shows windscreen haze (left picture) and reflection (right picture) effects on viewing objects through the windscreens.

Figure 6. Loss of Contrast Due To Windscreen Haze (Left) and Reflections in the Windscreen (Right)

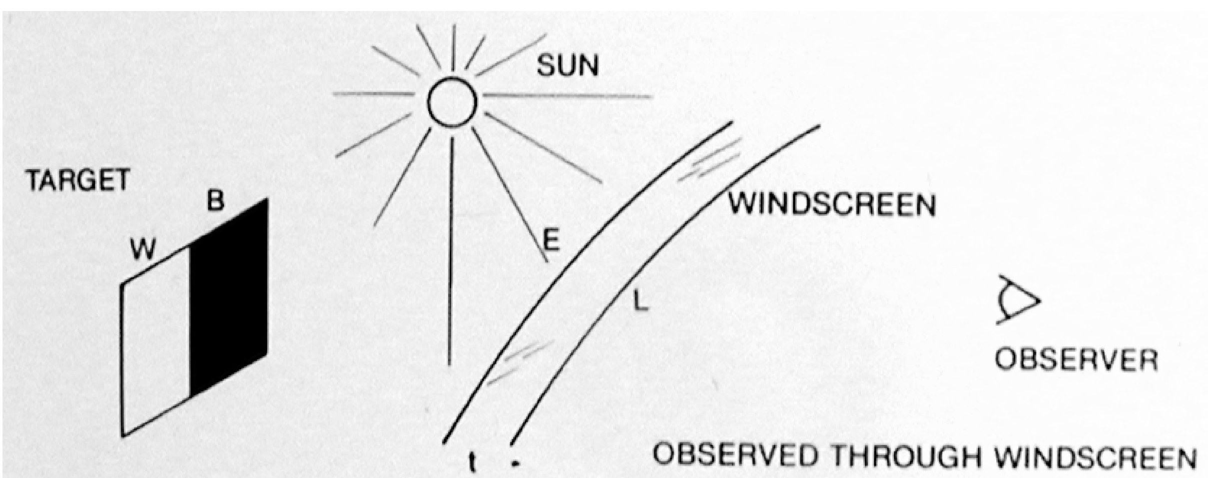


Figure 7. Basic Model of Contrast Loss through Aircraft Windscreen Due To Haze

Figure 7 is a diagram showing the basic components and geometry that can be used to derive the amount of contrast loss that might be expected due to windscreen haze (microscratches or micro-inclusions in the windscreen that scatter light). The same basic model can also be used to demonstrate how reflections in the windscreen from the dust/dirt on the glare shield cause contrast loss when viewing through the windscreen.

Referring to Figure 7 the TARGET consists of two elements labeled W for white and B for black (much like the refueling hose and its markings). These are the luminance of the white and black part of the TARGET (which depends on the amount of illumination falling on them). The basic contrast ratio of the TARGET object with no windscreen in the way is:

$$\text{Contrast ratio of the TARGET is } C_r = W/B \qquad (6)$$

Where: C_r = contrast ratio
W = luminance of the white part of the target
B = luminance of the black part of the target

Remember, the luminance of the white and black parts of the refueling hose depend on the reflection coefficient for the illuminating/viewing geometry as well as the amount of illumination falling on the hose.

If there is a veiling luminance caused by windscreen microscratches or dust/dirt on the windscreen this will give rise to a veiling luminance, L, that will appear super-imposed over the target object. The magnitude of the veiling luminance, L, is proportional to the illumination, E, falling on the windscreen. If the windscreen transmission coefficient is "t" then one can calculate the contrast ratio that will be observed by the pilot since the veiling luminance, L, will be added to both the white and black luminances of the TARGET object:

$$C_{or} = \text{observed contrast ratio} = W'/B' \qquad (7)$$

Where: C_{or} = observed contrast ratio
$W' = W*t + L$ = observed luminance of the white part of the target
$B' = B*t + L$ = observed luminance of the black part of the target

Substituting we get:

$$C_{or} = W'/B' = (W*t + L)/(B*t + L) = \text{observed contrast ratio} \qquad (8)$$

Now, the question is, how does the observed contrast ratio compare to the inherent contrast ratio of the TARGET object with no windscreen in place? For those of you that are gluttons for punishment please follow the argument/proof provided below:

One can divide both the numerator and denominator of the above equation to arrive at a slightly different equation that is in a better form for our proof development:

$$C_{or} = W'/B' = (W + L/t)/(B + L/t) = \text{observed contrast ratio in slightly different format} \qquad (9)$$

By the very definition of contrast ratio, namely that contrast ratio is the higher luminance divided by the lower luminance, one has the following starting point for this proof:

$$W > B \tag{10}$$

Next, let X = L/t to simplify the proof. Note that L/t is a quantity greater than zero.

Multiply both sides of inequality relationship (10) by X, and, since X is greater than 0 one gets:

$$W\,X > B\,X \tag{11}$$

Next, add W times B (or simply WB) to both sides of the inequality:

$$WB + WX > WB + BX \tag{12}$$

Next divide both sides by B:

$$(WB + WX)/B = W(B + X)/B > W + X \tag{13}$$

Now divide both sides of the inequality by (B+X) and we obtain:

$$W/B > (W + X)/(B + X) \tag{14}$$

Now we can substitute back in L/t for the X:

$$W/B > (W + L/t)/(B + L/t) \tag{15}$$

And finally, note that the term on the left is the inherent contrast ratio (C_r; see equation 6) and the term on the right is the observed (through the windscreen) contrast ratio (C_{or} see equation (9)), which means this simplifies to:

$$C_r > C_{or} \tag{16}$$

Which means the observed contrast will be lower than the contrast without the windscreen in place. Note that one obtains this same result for reflections except that the value of X would now be a quantity proportional to the reflectance coefficient of the windscreen. Note that the amount of contrast loss can be severe depending on the luminance levels involved. As an example, this laboratory has measured contrast loss of approximately 90% for A-10 windscreens/HUD combiner glasses due to Gatling gun gas residue on the windscreen prior to the installation of a gun-gas deflector. It all depends on sun illumination angles, windscreen quality, target luminances, and the transmission coefficient of the windscreen.

3 MEASUREMENT, PROCEDURES, AND RESULTS

A total of six hose samples were supplied by the Aerial Refueling Systems Advisory Group **(**ARSAG**)** for evaluation. The table and pictures below summarize the hose samples provided.

Table 1. The Six Hose Samples

Hose #	Descriptor
1	New Hose - measured 2.5" outside diameter (Black Hose W/White Markings like new or almost new)
2	Small Dia. Hose - measured 2.0" OD (Weathered Black Hose w/weathered White "Beige" Markings)
3	OMEGA Old White - measured 2.88" OD (Black Hose & White markings w/slight Chalking)
4	DURODYNE 62913, 841023AA1116, SN 0032 - measured 2.90" OD (Black Hose w/chalking transfer & White markings w/severe Chalking)
5	SARGENT-FLETCHER Co., DURODYNE INC., 72429/62913, 72429/401426, SN 0018 - measured 2.75" OD (Weathered White "Beige" Hose & Lighter white "Beige" markings)
6	Soiled Hose - measured 2.83"OD (Black w/gray scuff markings hose & Dirty-soiled White markings W/gray scuffing)

Visible spectrum photographs of each of these hose samples are provided below with a "pure white" Barium Sulfate ($BaSO_4$) reference surface located above the hose for comparison.

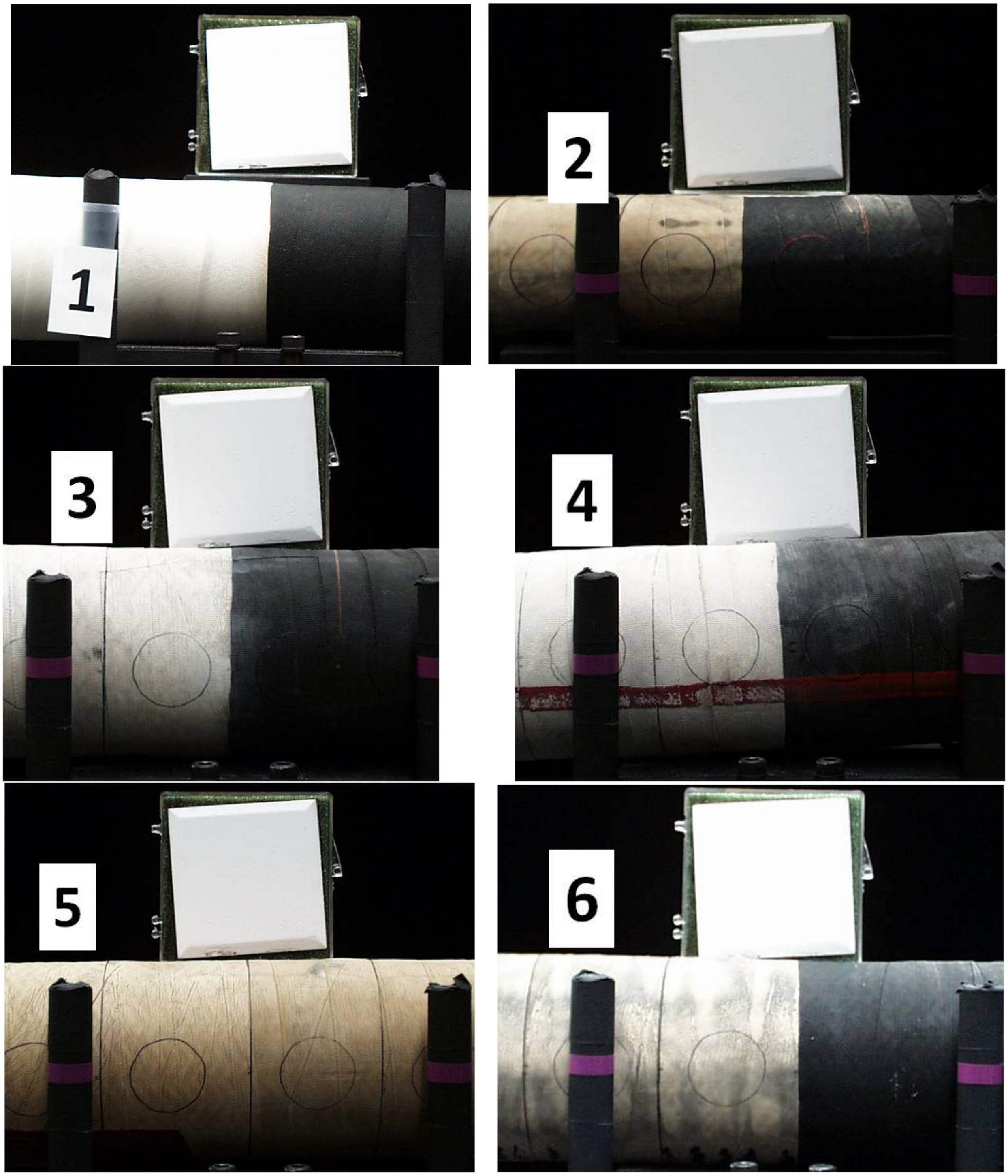


Figure 8. Hose Samples

The variations in lighting and exposures for the different photographs shown above make it difficult to precisely compare the different hoses samples (that is why measurements are made) but the photographs clearly show the basic differences between the new, unused hose sample (hose sample #1) and the others. Hose sample #5 is also somewhat different than the others in that it had a definite beige coloration to it and the reflectance difference between the light and dark parts of the hose are not that easy to see.

The circles seen on the hoses in each photograph were used to mark where the hose reflectance values were measured using the geometry shown in Figure 10.

Figure 9 is a photograph of all six hose samples evaluated for this effort. The purple stripes around each hose on either side of a demarcation between the light and dark parts of the hose mark the specific areas that were evaluated and photographed.

Figure 9. The Full Collection of Hose Samples Evaluated For This Effort

By looking at Figure 9 one can get a good qualitative idea of the range of hose diameters, markings, coloration, contrast and scuffing associated with the hoses evaluated for this effort. Subjectively, hoses 1, 3, and 4 look somewhat comparable regarding the white portions of the hose but hoses 3, and especially 4, show signs of white scuffing on the black sections of the hoses. This subjective assessment of the hoses is validated by Figures 13 and 15, which show the corresponding contrast ratios for these hoses to be similar (hose 1 with the highest contrast ratio followed by hose 3 and then hose 4 - all of which have better contrasts than the other 3 hoses.) The qualitative and quantitative assessments appear to be in harmony.

3.1 Photometric Reflectance - Non-Specular Illumination Geometry

The reflectance coefficients of each of the six hose samples were measured for several viewing/illumination geometries. This section deals with the reflection coefficients (from which the hose marking contrast ratios are calculated) that were measured using non-specular reflection geometries. Two general, non-reflecting geometries were used: viewing (measuring) perpendicular to the surface of the hose with illumination provided by light sources on either side of the viewing location (Fig 10) and viewing the hose from different view angles with the illumination provided from a single light source perpendicular to the hose (Fig 11).

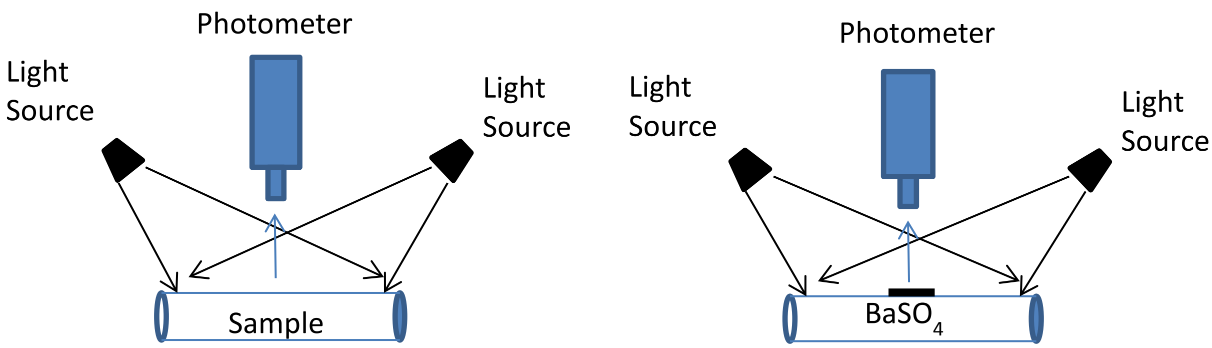


Figure 10. Measurement Perpendicular to the Surface, Illumination at 45 Degrees on Either Side

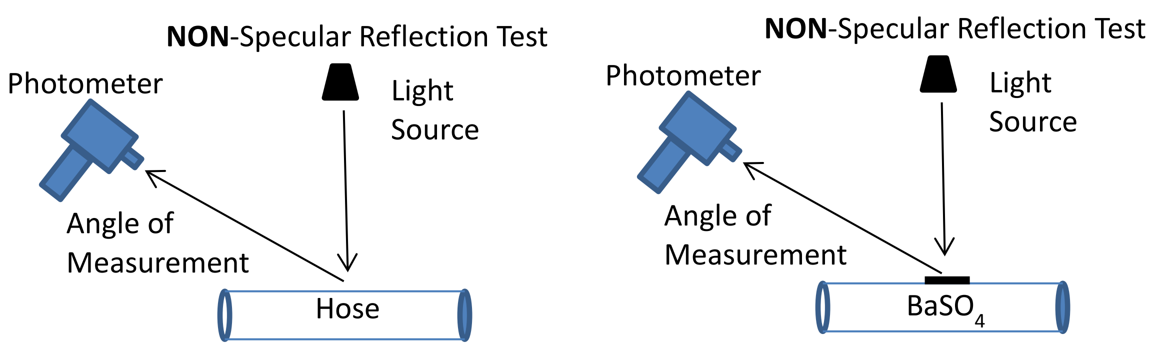


Figure 11. Illumination Perpendicular to the Surface, Viewing (Measurement) at Different Angles

In the case of Figure 10 the hose was measured in three different areas on either side of, and close to, the demarcation between the light and dark part of the hose, as shown in Figure 12. This provided a sample of reflectance coefficients (for this geometry) for each of the hoses.

Figure 12. The Measurement Locations for "Data Takes" A, B, and C (Compare to Circles Marked on Hose Samples in Figure 8)

Measurements collected for the non-specular reflectance geometry of Figure 10 are summarized in Table 2 below:

Table 2. Non-Specular Reflectance Data with Photometer Aimed Perpendicular to the Surface and Illumination Sources Provided On Either Side of the Photometer

Data take		Hose Number 1	2	3	4	5	6
Data Take A	Black Luminance	2.345	2.314	2.799	4.479	20.92	2.184
	BaSO4 Luminance	65.03	65.18	66.52	65.7	65.4	64.84
	Black Reflectance	0.036	0.036	0.042	0.068	0.320	0.034
	White Luminance	41.91	17.61	43.89	44.72	23.34	18.79
	BaSO4 Luminance	64.99	65.08	66.53	65.62	65.56	64.83
	White Reflectance	0.645	0.271	0.660	0.681	0.356	0.290
	Contrast Ratio	17.9	7.6	15.7	10.0	1.11	8.6
Data Take B	Black Luminance	2.165	2.647	2.552	3.19	19.76	2.28
	BaSO4 Luminance	64.9	65.06	66.59	65.62	65.81	64.92
	Black Reflectance	0.033	0.041	0.038	0.049	0.300	0.035
	White Luminance	44.43	17.97	39.46	43.36	23.35	20.18
	BaSO4 Luminance	64.99	65.02	66.53	65.5	65.4	64.96
	White Reflectance	0.684	0.276	0.593	0.662	0.357	0.311
	Contrast Ratio	20.5	6.8	15.5	13.6	1.19	8.8
Data Take C	Black Luminance	2.236	3.103	2.714	2.54	19.67	2.357
	BaSO4 Luminance	64.94	65.06	66.4	65.37	65.44	64.46
	Black Reflectance	0.034	0.048	0.041	0.039	0.301	0.037
	White Luminance	45.57	18.95	39.75	44.28	**23.7**	17.83
	BaSO4 Luminance	64.72	65.12	65.87	65.23	65.67	64.58
	White Reflectance	0.704	0.291	0.603	0.679	0.361	0.276
	Contrast Ratio	20.4	6.1	14.8	17.5	1.2	7.6

The unshaded cells are the raw data. For each "data take" section the first two shaded rows are the black reflectance coefficients and the white reflectance coefficients, respectively. The last shaded row for each "data take" is the calculated contrast ratio for each hose and that "data take."

Table 3 is a summary of the measurements collected for the non-specular reflectance geometry of Figure 11 showing the effects (or lack thereof) of viewing (measurement) angle on measured contrast ratio.

Table 3. Non-Specular Reflectance Data with the Light Source Aimed Perpendicular to the Surface and the View (Measurement) Angle Varied From 60 Degrees to 30 Degrees (See Figure 11)

View angle from Horz		Hose Number 1	2	3	4	5	6
60 degrees	Black Luminance	1.62	2.493	1.792	2.915	13.75	1.6
	BaSO4 Luminance	43.56	45.74	43.17	43.65	43.05	44.37
	Black Reflectance	0.037	0.055	0.042	0.067	0.319	0.036
	White Luminance	28.94	13.82	28.64	27.36	15.73	12.61
	BaSO4 Luminance	44.06	45.97	43.11	43.76	43.2	44.44
	White Reflectance	0.657	0.301	0.664	0.625	0.364	0.284
	Contrast Ratio	17.7	5.5	16.0	9.4	1.14	7.9
45 degrees	Black Luminance	1.521	1.656	1.7	2.707	13.17	1.58
	BaSO4 Luminance	43.08	42.14	42.24	42.57	42.56	43.08
	Black Reflectance	0.035	0.039	0.040	0.064	0.309	0.037
	White Luminance	27.12	11.88	27.57	26.29	14.93	11.47
	BaSO4 Luminance	43.18	42.53	42.23	42.62	42.66	43.39
	White Reflectance	0.628	0.279	0.653	0.617	0.350	0.264
	Contrast Ratio	17.8	7.1	16.2	9.7	1.13	7.2
30 degrees	Black Luminance	1.467	1.622	1.749	2.585	12.46	1.562
	BaSO4 Luminance	41.38	40.63	42.76	40.68	40.84	41.57
	Black Reflectance	0.035	0.040	0.041	0.064	0.305	0.038
	White Luminance	26.06	11.13	27.98	25.38	**14.32**	10.21
	BaSO4 Luminance	41.4	40.72	42.79	40.65	40.66	41.55
	White Reflectance	0.629	0.273	0.654	0.624	0.352	0.246
	Contrast Ratio	17.8	6.8	16.0	9.8	1.15	6.5

As in the previous table, the raw data are in the unshaded cells and the first two shaded rows for a specific measurement angle are the black and white reflectance coefficients respectively. The third shaded row for each measurement angle section is the calculated contrast ratio for that hose and for that particular viewing (measurement) angle.

The following table and graphs are provided to more easily see the results presented in Table 2. Table 4 is a summary of the contrast ratios calculated from each of the 3 spot pairs (A, B, and C) for which reflectance coefficients were determined. Since these hose sections are not uniform in their reflectance coefficients (as is obvious from the hose sample pictures in Figure 8), this procedure was intended to provide an indication of how much the hose contrast ratio may vary depending on where on the hose measurements were made. Table 4 shows that, for this measurement geometry, average contrast ratios range from a high of 19.6 for hose sample number 1 (the new hose) to a low of 1.2 for the old, beige hose sample number 5. The variations in contrast ratio for hose number 4 reflect the great degree of white "scuffing" apparent on the black section of the hose. The three measurements of the white sections of this hose were fairly close together (see Table 4) but the black section reflectance coefficient measurements varied depending on how much of a white "scuff" mark was within the measurement area.

Table 4. Summary of Contrast Ratios Measured Perpendicular to the Hose Surface

Data Take	Hose Number 1	2	3	4	5	6
A	17.9	7.6	15.7	10.0	1.11	8.6
B	20.5	6.8	15.5	13.6	1.19	8.8
C	20.4	6.1	14.8	17.5	1.20	7.6
Avg:	**19.6**	**6.8**	**15.3**	**13.7**	**1.2**	**8.3**
Stdev:	1.49	0.76	0.48	3.74	0.05	0.69
% Stdev:	7.6	11.1	3.1	27.3	4.1	8.3

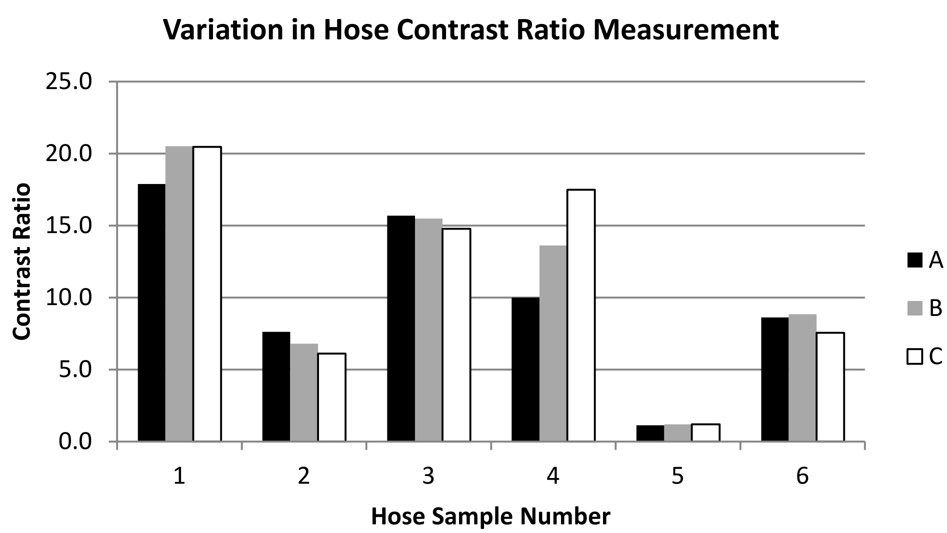


Figure 13. Bar Graph of the Contrast Ratios Measured Perpendicular to the Surface

Figure 13 is a bar graph of the contrast ratio data presented in Table 4. From this graph it is easy to see the new hose (hose #1) has the highest average contrast ratio, hose #4 has the greatest variation in contrast ratio (for the points sampled), and hose #5 has the worst contrast ratio of all of the hoses.

The significance (or non-significance) of these results is discussed in the Analysis and Discussion section (4.0). However, at this time it is probably instructive to look at the contrast results presented in Table 4 and Figure 13 after they have been converted to *modulation contrast* using equation 2 (times 100 to get percent).

Table 5. Summary of Modulation Contrast Measured Perpendicular to the Hose Surface

Data Take	Hose Number 1	2	3	4	5	6
A	89.4	76.8	88.0	81.8	5.35	79.2
B	90.7	74.3	87.9	86.3	8.64	79.7
C	90.7	71.8	87.3	89.2	9.12	76.6
Avg:	**90.3**	**74.3**	**87.7**	**85.8**	**7.7**	**78.5**
Stdev:	0.74	2.48	0.37	3.71	2.05	1.65
% Stdev:	0.8	3.3	0.4	4.3	26.7	2.1

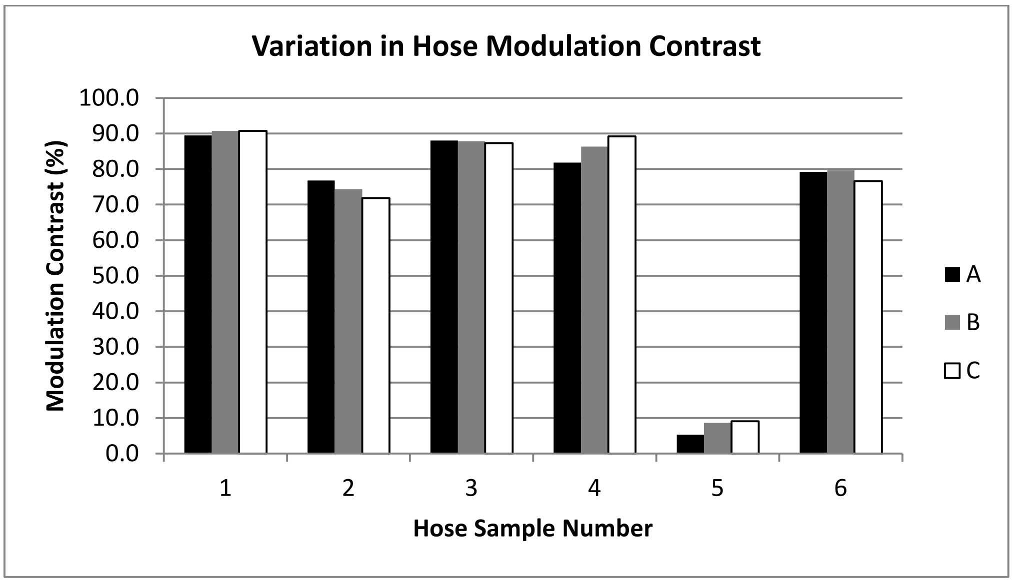


Figure 14. Bar Graph of the Modulation Contrast Data of Table 6

Looking at the same data converted to modulation contrast provides a slightly different perceptual impression of the results. A look at Table 6 now shows that the hose that has the greatest percent standard deviation (most variance) with respect to the 3 "data takes" (A, B, and C) is hose number 5 with a standard deviation of 26.7%. When the data were analyzed in the contrast ratio format it was hose number 4 that had the greatest standard deviation with a value of 27.3% (from Table 4). Also, in Figure 14 all of the hoses appear to have a fairly high modulation contrast with the exception of hose number 5. This compares to a more distributed set of contrast ratios for the different hoses as seen in Figure 13. The only reason for conducting this exercise is to caution the reader from coming to possibly erroneous conclusions based on the appearance of these contrast (ratio or modulation) graphs.

The following table (Table 6) is a summary of the contrast ratios extracted from Table 3 that were measured using the geometry of Figure 11 wherein the illumination source is perpendicular to the hose but the view (measurement) angle is varied from 60 degrees to 30 degrees as measured from the longitudenal axis of the hose. Figure 15 shows the data in Table 3 in graphic form. It is apparent from these data that the contrast ratio between the light and dark parts of the hose don't change very much as a function of viewing angle (at least for the angles measured).

Table 6. Contrast Ratio as a Function of Viewing Angle with Illumination Perpendicular to the Hose

View angle (deg)	Hose Number 1	2	3	4	5	6
60	17.7	5.5	16.0	9.4	1.14	7.9
45	17.8	7.1	16.2	9.7	1.13	7.2
30	17.8	6.8	16.0	9.8	1.15	6.5

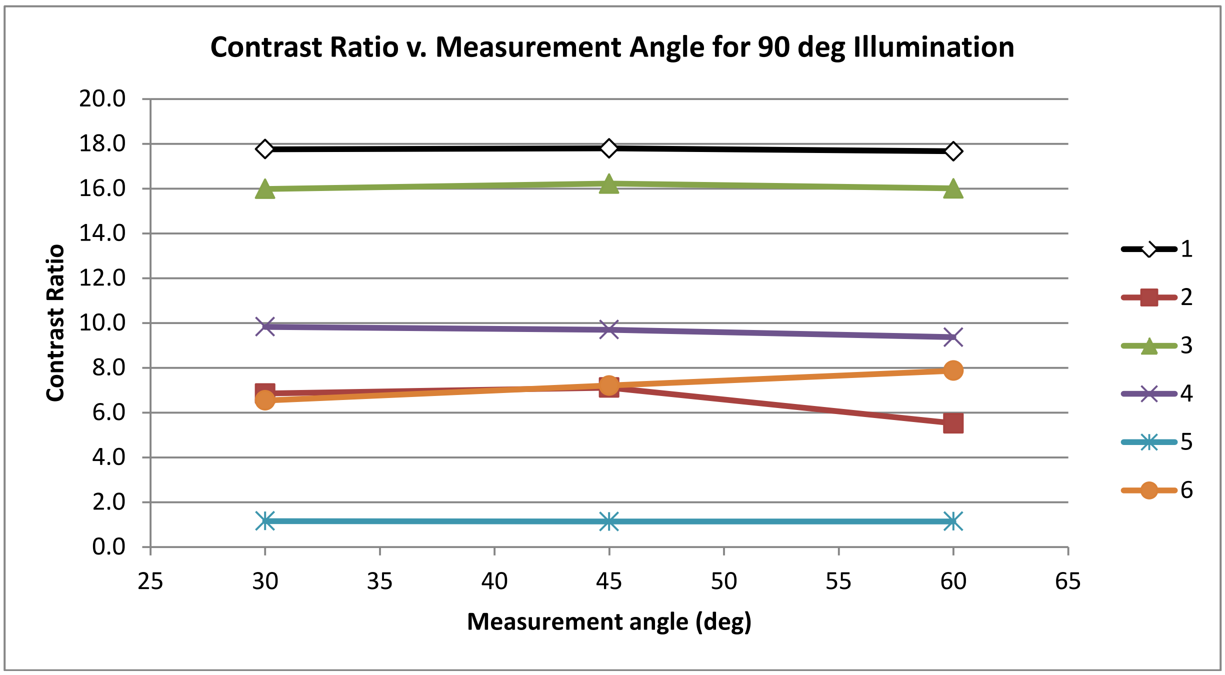


Figure 15. Graph of Contrast Ratio versus Viewing (Measurement) Angle from Table 6

Much like the previous contrast ratio measurement with the illumination source to the sides and the view/measurement angle perpendicular to the surface the new hose (number 1) is superior to all of the others with hose number 2 coming in at a fairly close second and hose number 5 easily in last place with the poorest contrast ratio by far. Note that hose number 5 does not even come up to the contrast ratio that was considered to be absolute minimum based on the discussion in section 2.4 (a suggested absolute minimum of 1.2 contrast ratio).

From the following Tables 7 and 8, which were extracted from Table 3 it is apparent that both the black and white reflectance coefficients remain relatively constant independent of the view/measurement angle. It is also apparent from Tables 7 and 8 that the new hose sample (number 1) achieves its high contrast from a combination of a good, low black level and a relatively good, high white level. However, from Table 7 one can see that hose number 6 has about the same black level reflectance as the new hose number 1 (number 6 loses contrast ratio because of its relatively "dirty" white reflectance). In addition, from Table 8 one can see that the white part of hose 1 (the new one) is not quite as reflective as the white part of hose number 3. The main take-away from this is that in order to make inteligent decisions regarding hose replacement or hose cleaning one needs to look at the individual reflection coefficients not just the more global contrast ratio.

Table 7. Summary of the "Black" Reflectance Coefficients as a Function of View Angle Extracted From Table 3 for Each of the Hose Samples

View angle (deg)	Black reflectance coefficient Hose Number 1	2	3	4	5	6
60	0.037	0.055	0.042	0.067	0.319	0.036
45	0.035	0.039	0.040	0.064	0.309	0.037
30	0.035	0.040	0.041	0.064	0.305	0.038

Table 8. Summary of the "White" Reflectance Coefficients s a Function of View Angle Extracted From Table 3 for Each of the Hose Samples

View angle (deg)	White reflectance coefficient Hose Number 1	2	3	4	5	6
60	0.657	0.301	0.664	0.625	0.364	0.284
45	0.628	0.279	0.653	0.617	0.350	0.264
30	0.629	0.273	0.654	0.624	0.352	0.246

3.2 Specular (Mirror-Like) Effects - Effect of Equal Viewing and Illumination Angle

The objective of this set of measurements was to determine how much the reflectance coefficient of the various hoses change as a function of the viewing angle for a specular reflection geometry. This was only done for the visible light spectrum (nominally 400-700 nm) using the hand-held photometer. Data were collected for 3 different viewing and lighting angles. Figure 16 shows the basic equipment set-up for this measurement.

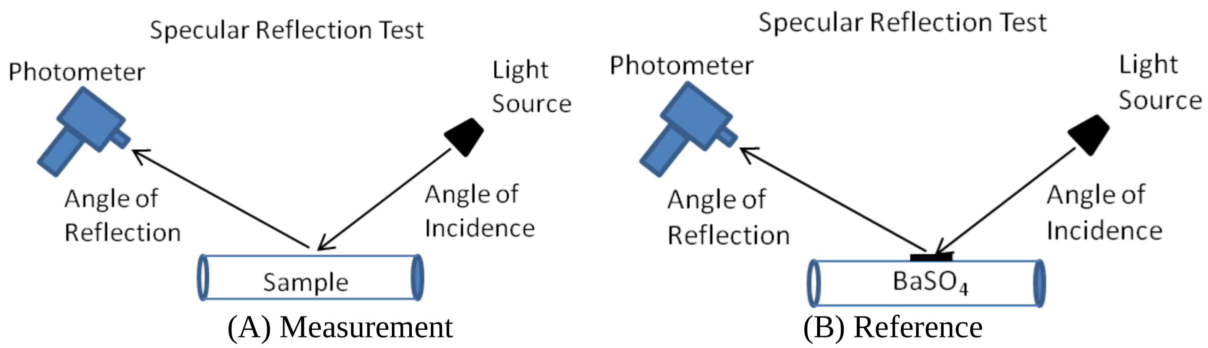


Figure 16. Basic Geometry for Measuring Specular (Mirror-Like) Reflectivity Effects

Figure 16 (A) depicts the measurement of the apparent luminance of the refueling hose (both the light and dark parts separately) due to the directional illuminance provided by the light source. The (B) figure depicts how the reference surface (BaSO4 plate) is measured at the same angles to determine what the perfect Lambertian reflector surface would produce in the way of luminance under the same illumination and angle conditions. The ratio of these two readings (the "A" reading and the "B" reading) is the reflection coefficient for the section of hose sample measured (the light or dark part) for the illumination and viewing angle used. Measurements were made for viewing/measurement angles of 30 degrees, 45 degrees, and 60 degrees.

Figure 17. Physical Set-Up to Measure Specular Reflectivity

The refueling hose sample was placed between the uprights shown at the left side of Figure 17. The light source and photometer are at the right side of the photograph. The optical rails mounted to the table top were set for viewing/reflection angles of 30, 45, and 60 degrees from parallel to the surface of the sample. That makes 60 degrees the "steepest" viewing angle with respect to the surface and the angle at which one would expect the least specular effects and 30 degrees should be the angle that we see the highest specular effects (if any are present). Figure 18 is a view from just behind the photometer with the photometer set up in the 60 degree viewing angle and aimed at the white part of the hose sample. The BaSO4 reference surface was placed between the two black uprights shown in the center of the picture when it was time to measure the reference luminance produced by the illumination source (which is "off-picture" to the right).

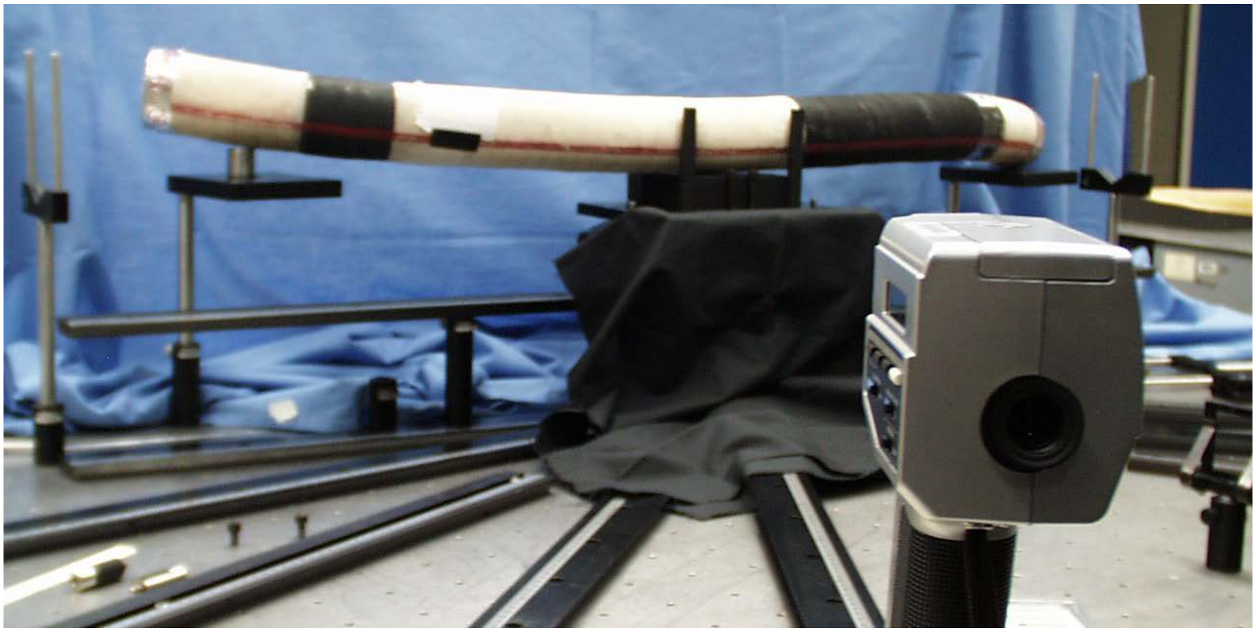


Figure 18. View From Behind the Photometer for White Portion of Hose Measurement at 60 Deg Angle

The measurement set-up in Figure 18 was accomplished for light and dark sections of all six hose samples and all three viewing/illumination angles. From these data the reflection coefficients of the light and dark part of the six hose samples was calculated for the 3 viewing/illumination angles. Table 9 is a summary of these results.

Table 9. Summary of Specular Reflection Effects

Angle from horz	Item	Sample Number 1	2	3	4	5	6
60 degrees	Black Luminance	3.8	6.92	6.24	8.68	29.34	4.88
	BaSO4 Luminance	103.9	103.3	106.1	103.9	104.7	104.5
	Black Reflectance	**0.037**	**0.067**	**0.059**	**0.084**	**0.280**	**0.047**
	White Luminance	71.88	34.42	41.33	50.85	47	31.9
	BaSO4 Luminance	103.2	103.1	105.1	104.2	103.1	102.1
	White Reflectance	**0.697**	**0.334**	**0.393**	**0.488**	**0.456**	**0.312**
	Contrast Ratio	**19.0**	**5.0**	**6.7**	**5.8**	**1.6**	**6.7**
45 degrees	Black Luminance	3.63	11.39	9.2	9.59	23.27	5.04
	BaSO4 Luminance	81.52	82.42	83.76	82.22	81.9	78
	Black Reflectance	**0.045**	**0.138**	**0.110**	**0.117**	**0.284**	**0.065**
	White Luminance	55.2	34.36	33.68	34.57	47	20.96
	BaSO4 Luminance	82.5	80.31	82.77	80.91	82.93	81.23
	White Reflectance	**0.669**	**0.428**	**0.407**	**0.427**	**0.567**	**0.258**
	Contrast Ratio	**15.0**	**3.1**	**3.7**	**3.7**	**2.0**	**4.0**
30 degrees	Black Luminance	4.92	22.47	16.46	15.14	19.04	8.07
	BaSO4 Luminance	59.08	62.25	60.91	60.81	62.42	60.44
	Black Reflectance	**0.083**	**0.361**	**0.270**	**0.249**	**0.305**	**0.134**
	White Luminance	39.52	43.33	35.18	28.12	68.7	13.44
	BaSO4 Luminance	60.52	60.51	60.92	55.87	61	58.16
	White Reflectance	**0.653**	**0.716**	**0.577**	**0.503**	**1.126**	**0.231**
	Contrast Ratio	**7.8**	**2.0**	**2.1**	**2.0**	**3.7**	**1.7**

The white data cells in Table 9 are the raw luminance measurements using the previously described geometry and technique. The lightly shaded cells are the reflectance coefficients calculated from the raw data and the more heavily shaded cells are the resultant contrast ratio values (light hose section divided by dark hose section) calculated for each hose and viewing angle.

In order to more easily see what is going on in Table 9 with respect to specular effects and differences between the hose samples it is perhaps easier to look at a graph of the results of just the contrast ratio calculations for the hoses and angles. Figure 19 does just that.

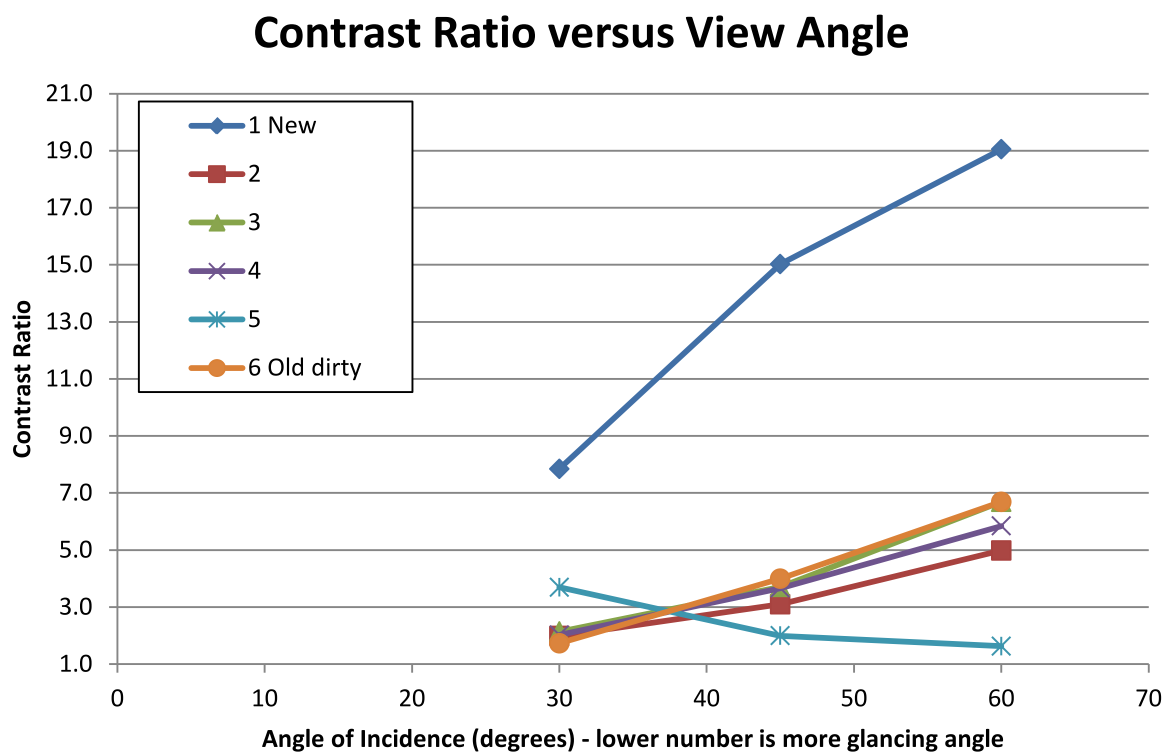


Figure 19. Summary Graph of Contrast Ratio as a Function of Viewing/Illuminating Angle for the Six Hose Samples Tested (Note: A Contrast Ratio of 1 Is the Lowest One Can Achieve - No Contrast)

The most striking feature of Figure 19 is the clear superiority of the new hose sample compared to the other samples with respect to the contrast between the light and dark part of the hoses. A second feature worth noting is that, unlike the non-specular reflection geometry measurements of Section 3.1, all hose samples show a definite decreasing contrast as the viewing angle becomes shallower (closer to looking along the line of the hose as opposed to looking at the hose perpendicular to its surface) with the notable exception of hose sample #5. These results and the absolute contrast ratios measured will be discussed more fully in the Analysis and Discussion section.

In order to get a better "picture" of the available contrast of the refueling hose samples other than the new one (hose sample #1), it is instructive to look at a graph that does not contain hose sample #1. Figure 20 is a graph of hose samples 2 through 6. It is apparent from this figure that hose samples 2 through 6 all exhibit similar reductions in contrast ratio for shallower angles (angles of view and illumination closer to the axis of the hose) with the notable exception of hose sample #5, which is discussed in more detail below. Another key point is that, with the exception of hose sample #5, the contrast ratio will most likely continue even lower as the view angle becomes smaller. This is a potentially disturbing point in that the pilot's view along the hose can easily go below the 30 degree angle, which was the lowest angle measured.

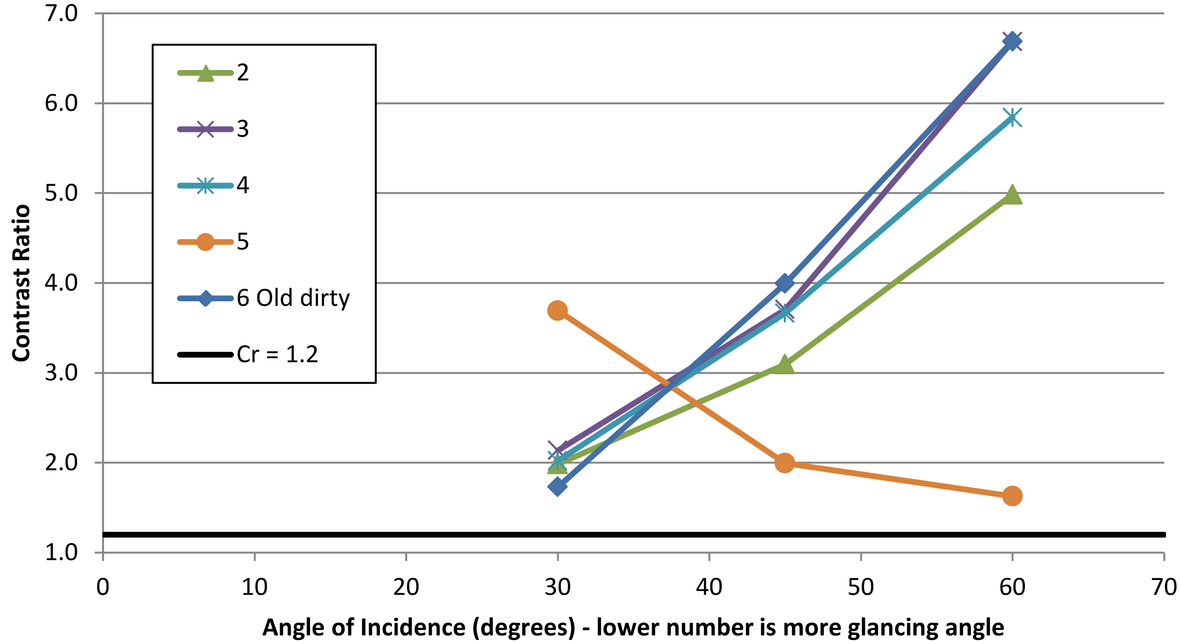


Figure 20. Graph of Contrast Ratio versus View Angle for Hose Samples #2 Through #6

The horizontal black line toward the bottom of Figure 20 marks a contrast ratio of 1.2 on the graph. Judging by the rapid decrease in contrast ratio for all "old" hose samples (with the exception of hose sample #5) it is apparent that the contrast ratio could fall below the 1.2 contrast ratio criterion line for view angles in the range of 10 to 20 degrees. Note that it is not that one cannot see contrast ratios in this lower range but the lower contrast ratios (and relatively small size of the distant hose markings) can make it more difficult to see (taking more time to focus attention on the hose).

Contrast ratio is the ratio of the reflectance coefficients for the light and dark parts of the hose as previously noted. It is constructive to look at the actual reflectance coefficients for these hose samples to see how they combine to produce these contrast ratio results. This may give us some insight into what is happening to produce the lower contrast ratios for the lower view/illumination angles. Figures 21 and 22 are graphs of the light and dark sections of these hose samples respectively.

There are several points to note in the graphs of Figures 21 and 22 starting with the reflectance coefficients of the new hose, hose #1. First, the "white" part of the hose has a reflectance coefficient that ranges from about 0.65 (65%) to about 0.70 (70%) depending on the view angle. The relative flatness (uniformity of values) of the hose #1 curve in Figure 21 indicates it is fairly good at scattering light uniformly in all directions independent of the direction of the light or the viewing angle. Also, these values are among the hightest values of all the hose samples. We also see that "new" hose #1 has the "blackest black" reflection coefficients (lowest values) for the black part of the hose according to the hose #1 graph in Figure 22. It is this relatively consistent (across view angles) combination of a "whiter white" and a "blacker black" that give this hose sample the best contrast ratio for all view/illumination angles. Not surprising since the white has not been degraded darker by use and the black has not been "lightened" by scuffs from use as well.

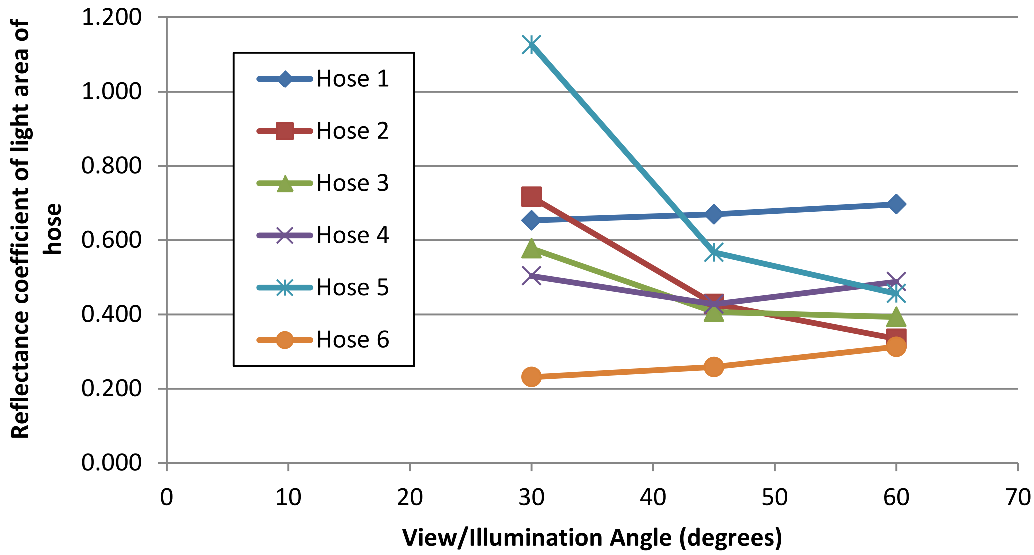


Figure 21. Reflectance Coefficients versus View Angle for the "White" Part of the Hose Sample

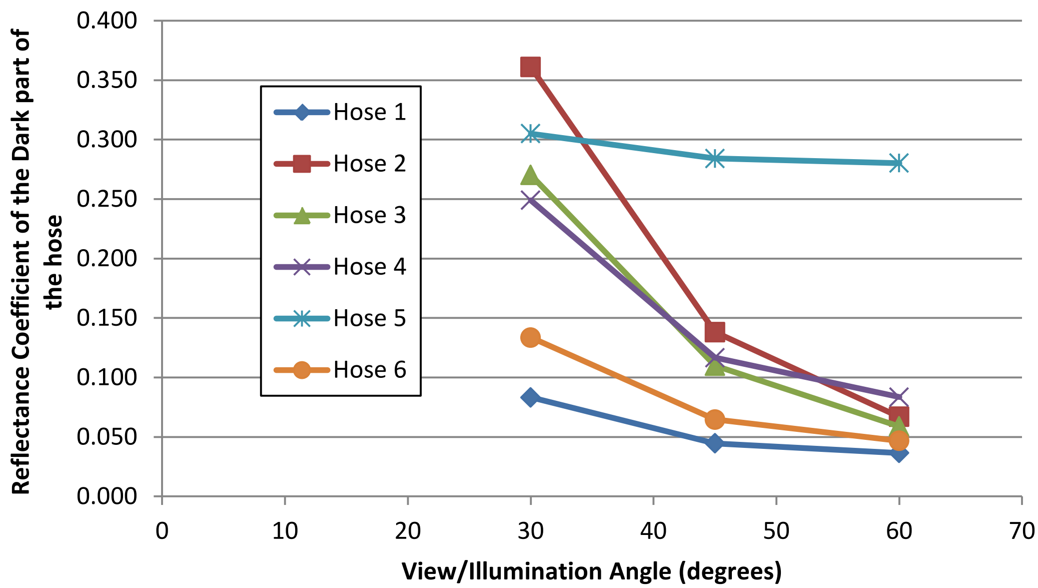


Figure 22. Reflectance Coefficients versus View Angle for the Dark Part of the Hose Samples

However, even for the "new" hose sample #1, note that the "black" reflection coefficient rises a fair amount (percentage-wise) going from the steeper 60 degree angle to the shallower 30 degree viewing angle. This suggests that the black part of this hose suffers a bit more than the white part of the hose with respect to specular (mirror-like) reflection viewing/lighting geometries. The other hoses show similar effects with the notable exception of hose sample #5.

Hose #5 has a fairly uniform, although somewhat high, "black" reflectance coefficient independent of view/illumination angle. From Table 9 it can be seen that its "black" reflectance coefficient values range from 0.284 to 0.305 as the view angle goes from 60 degrees down to 30 degrees. This implies the "black" part has a fairly mild specular aspect in that the percentage change as a function of angle is not very much. However, the "white" part of hose #5 has a fairly significant increase in reflection coefficient going from 0.456 to 1.126 as the view angle goes from 60 degrees down to 30 degrees. This is a fairly high increase (percentage-wise) and indicates that the white sections seem to have a significant "shiny" aspect (significant specular reflection effects) compared to the "black" sections. It is this "shiny" aspect of the "white" sections that causes this hose sample to actually increase in viewed contrast ratio as the view angle becomes more shallow. However, although not measured, this shiny aspect may also cause a significant loss of contrast ratio if the view angle and the illumination angle are not equal and opposite. For example, if the light source were off to one side of the hose (as in Figure 1) and the view angle were along the hose this shiny aspect might result in significantly less contrast.

3.3 Photographic Documentation

The purpose of this section is to provide photographic documentation to augment the quantitative data collected. In the case of different spectral bands, the equipment required to make quantitative measurements was not available, but the photographs in this section provide at least an idea of whether or not the hose samples show similar contrast levels as the visible spectrum, which was measured extensively. The visible band photographs, Figure 8, are repeated here to allow for an easier qualitative comparison between the visible spectral band and the other three sensors (NVGs, SWIR, and LWIR). This section also contains documentation photographs for the specular reflection issue.

3.3.1 Spectral Band Photographs for NVGS, SWIR, and LWIR

The following pages show pictures in the visible, SWIR, and LWIR wavelengths arranged for relatively easy comparison. Note that the long-wave infrared (LWIR) images have very little contrast because they are based on the temperature differences across the hose. With the LWIR sensor set to "white hot" the parts of the hose that have a higher temperature appear lighter than the parts of the hose that have a lower temperature. The LWIR pictures were taken with a 600 watt incandescent flood lamp (42 inches away) and two 60 watt incandescent lamps (20 inches away) illuminating the hose (see Figure 23 for about 10 minutes. The blacker parts of the hose tended to soak up the energy better than the white, reflecting part of the hose resulting in a contrast reversal (the black part of the hose appears brighter than the white part of the hose because the black part is hotter). Since the illumination sources provided only moderate irradiation the temperature differences between the two parts of the hose were quite small, resulting in very low contrast as seen with the LWIR sensor. In full direct sunlight the hose would probably produce a higher temperature difference. The SWIR images were recorded using two, 60watt incandescent lamps to irradiate the hoses.

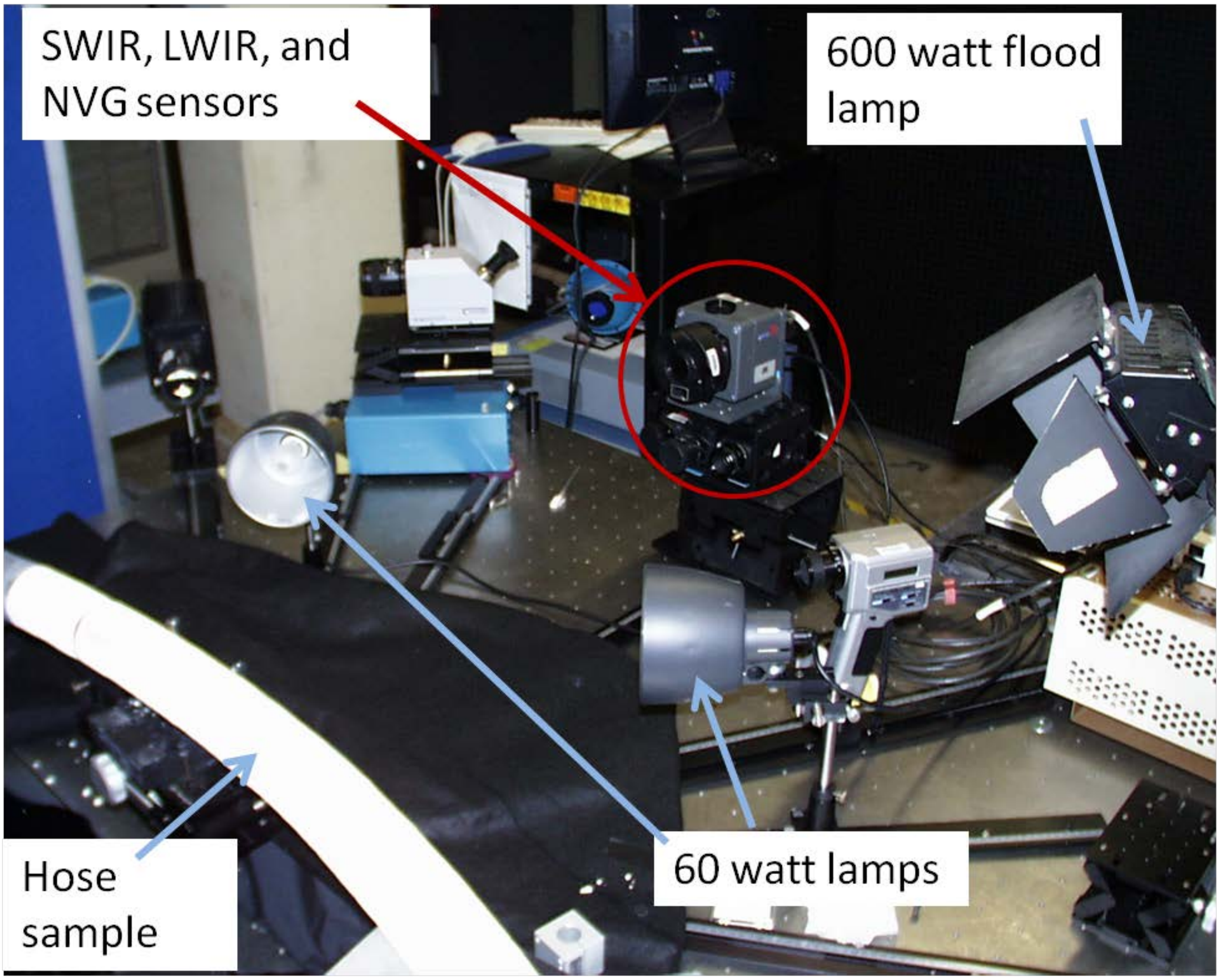
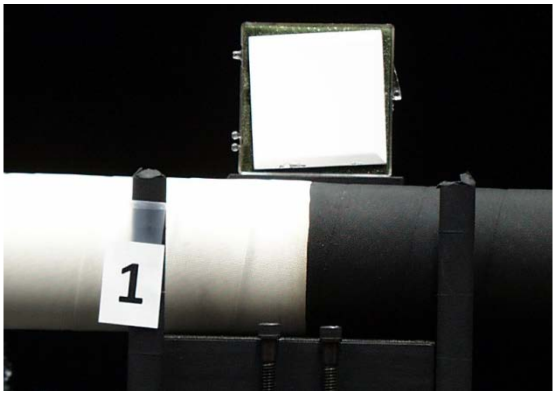
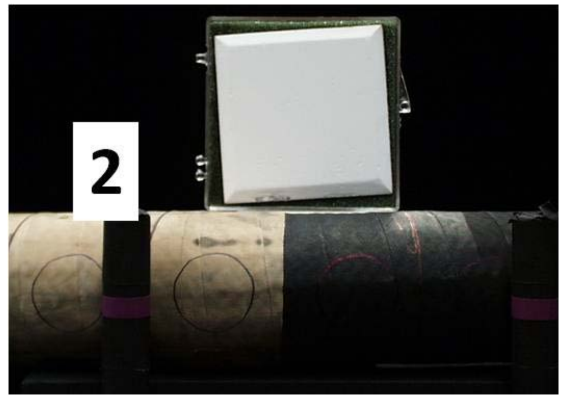


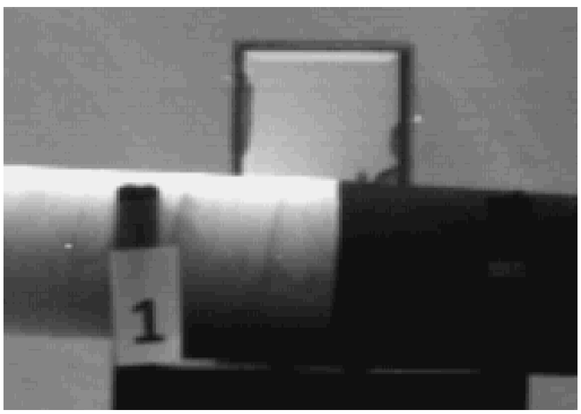
Figure 23. Set Up for Obtaining the SWIR and LWIR Images. The SWIR Images Were Recorded With Only the 60 Watt Bulbs Activated and the LWIR Images Were Obtained With both the 60 Watt Lamps and the 600 Watt Flood Lamp Activated



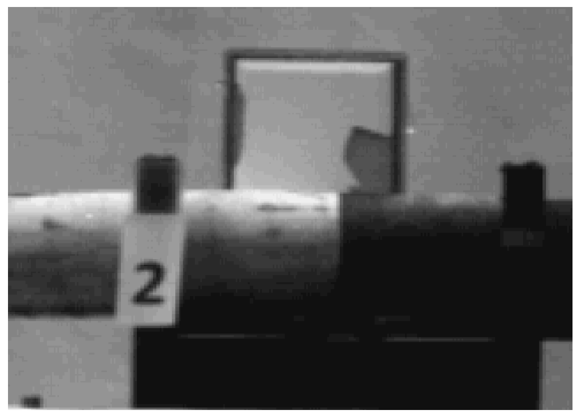
Hose 1. VISIBLE light.



Hose 2. VISIBLE light.



Hose 1. SWIR.



Hose 2. SWIR.


Hose 1. LWIR.

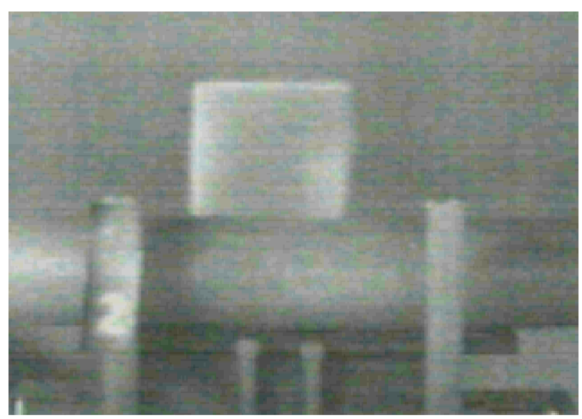
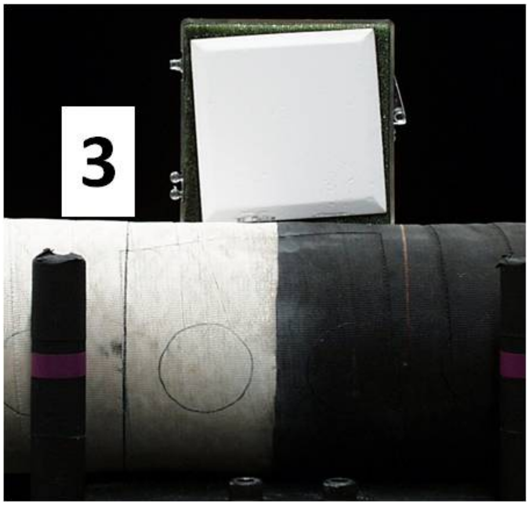
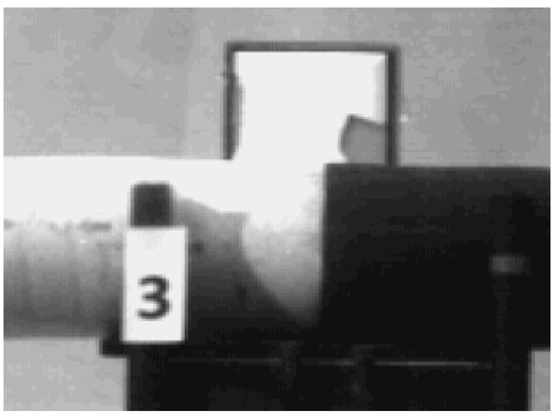

Hose 2. LWIR.

Figure 24. Comparison of Visible, SWIR, and LWIR Images for Hoses 1 and 2

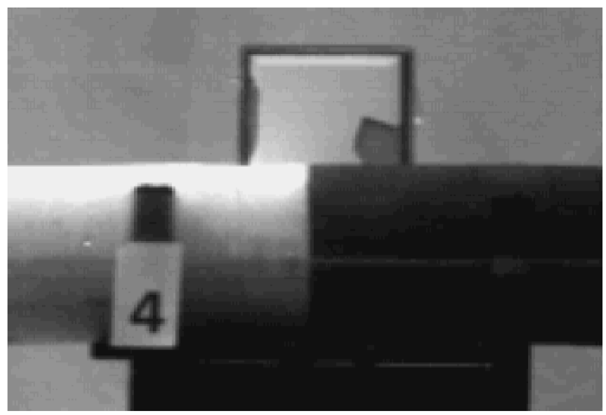


Hose 3. VISIBLE.

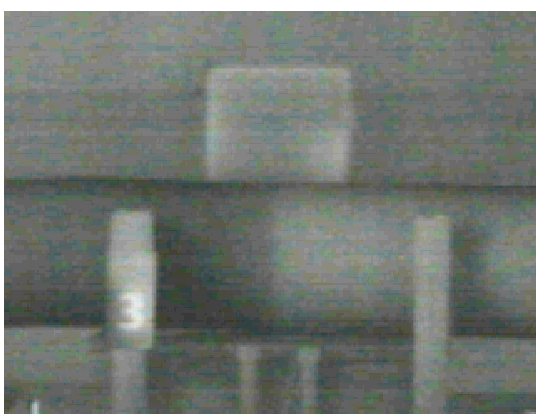
Hose 4. VISIBLE.



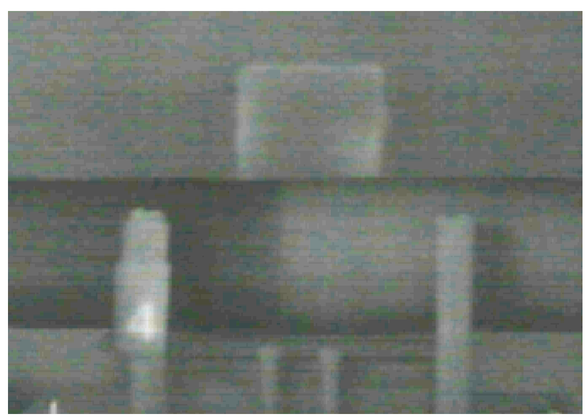
Hose 3. SWIR.



Hose 4. SWIR.

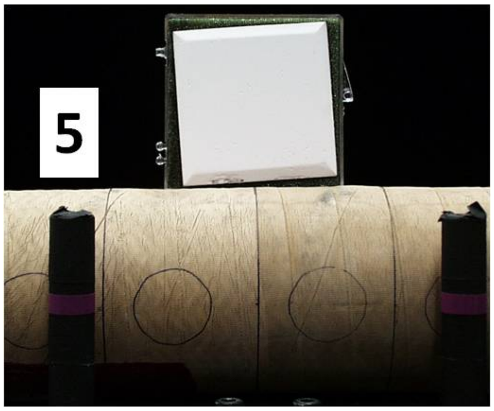


Hose 3. LWIR.

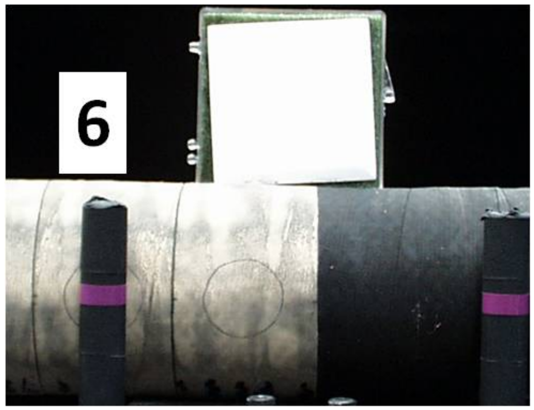


Hose 4. LWIR.

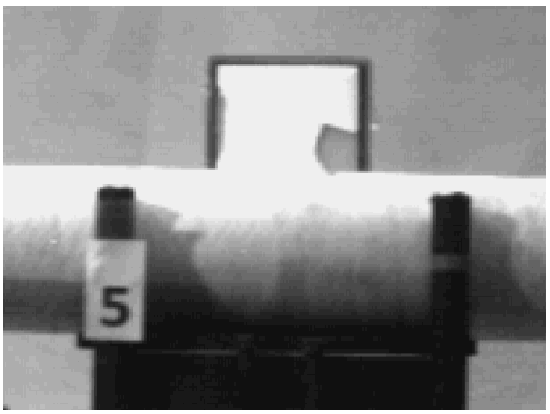
Figure 25. Comparison of Visible, SWIR, and LWIR Images for Hoses 3 and 4



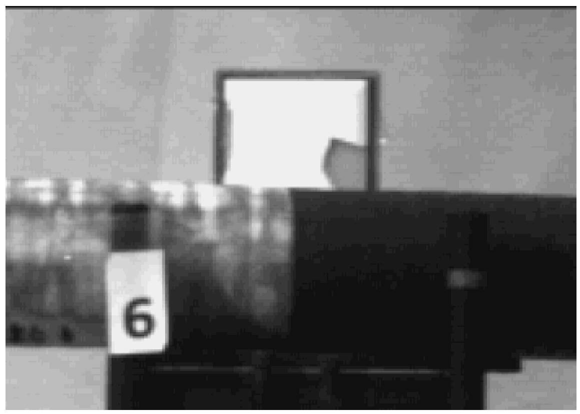
Hose 5. VISIBLE.



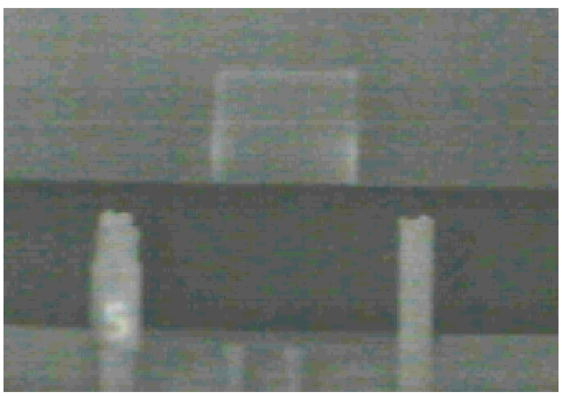
Hose 6. VISIBLE.



Hose5. SWIR.



Hose 6. SWIR.



Hose 5. LWIR.

Hose 6. LWIR.

Figure 26. Comparison of Visible, SWIR, and LWIR Images for Hoses 5 and 6

The following pictures provide a comparison between visible and NVG pictures of the hoses:

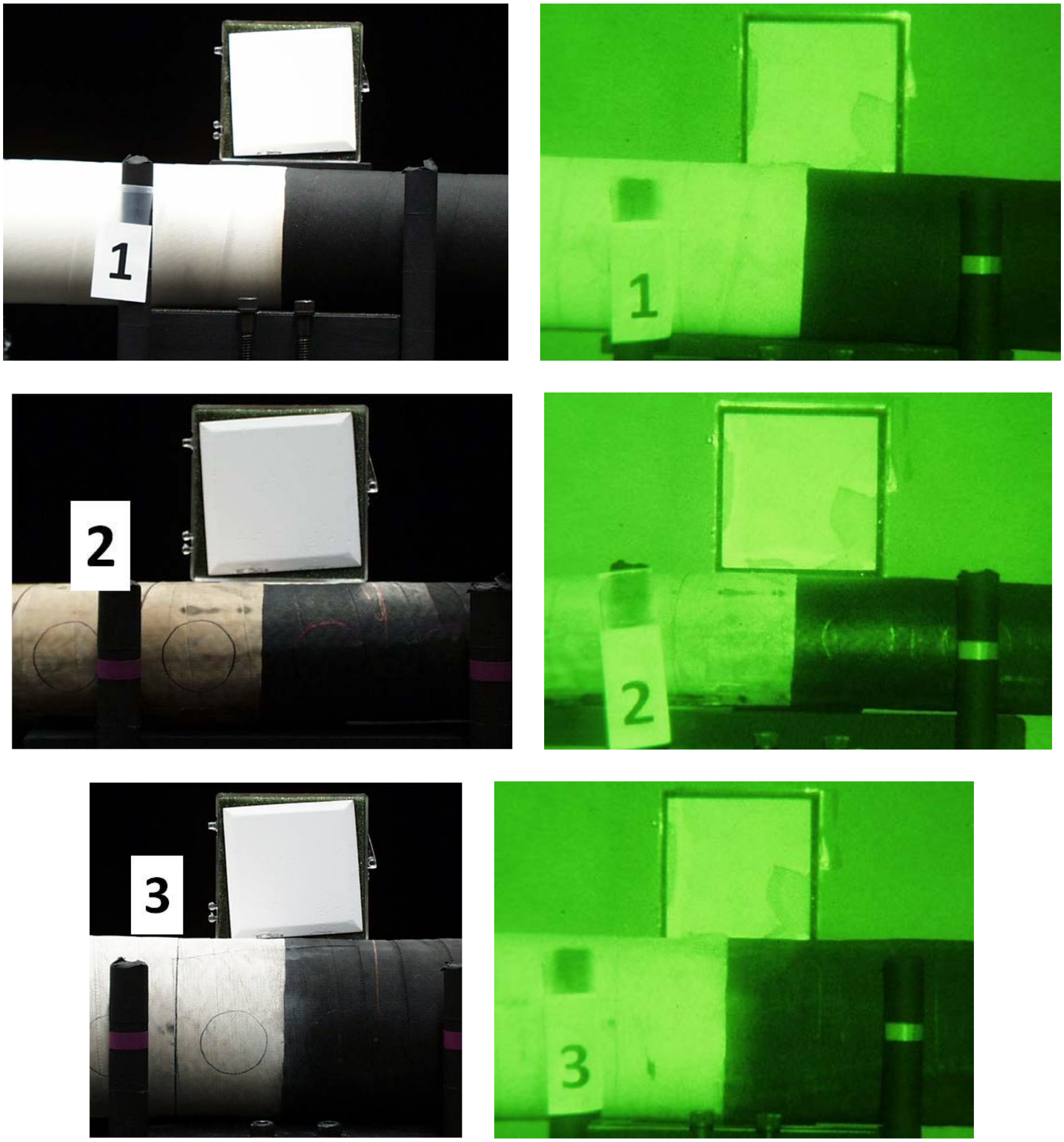


Figure 27. Comparison of Visible (Left) and NVG (Right) Images for Hoses 1 through 3

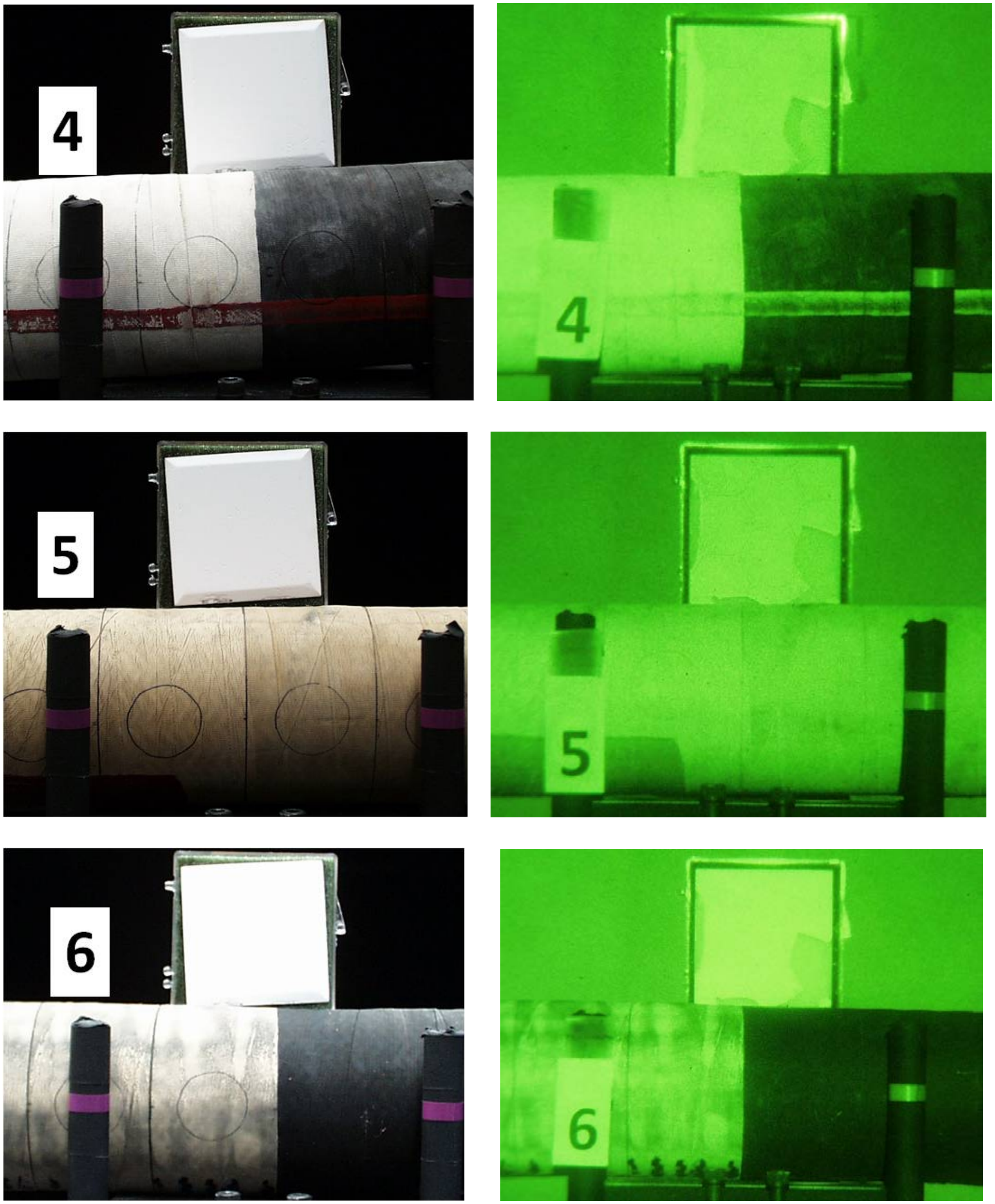
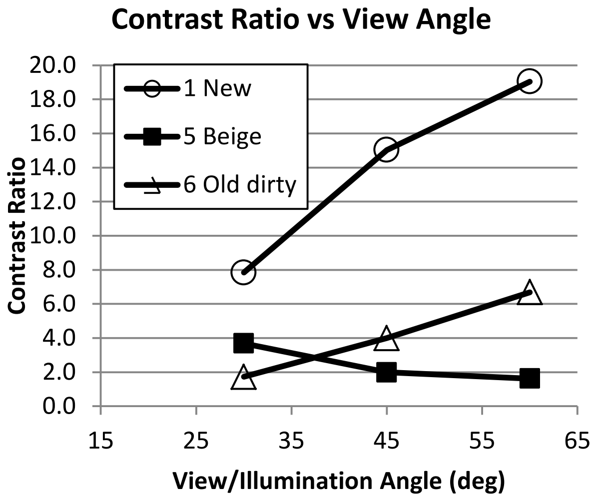


Figure 28. Comparison of Visible (Left) and NVG (Right) Images for Hoses 4 through 6

3.3.2 Specular Effects (Mirror-Like Reflections) Due To View/Illumination Angles.

The pictures and graphs below document the possible effects of "glint" due to the surface of the hose. Documentation photos were produced for hoses 1 (new), 5 (beige hose - old), and 6 (old

B&W hose). The photographs provide a general idea of what is happening as the hose samples are viewed at an angle but the photographic exposure level and illumination levels are not the same for the various pictures, which can cause the photos to be misleading. However, the change in contrast as a function of view/illumination angle is evident and is graphed (for all 3 hoses) in the upper left corner of each figure. Also, in the upper left corner of each *photograph* is a $BaSO_4$ reference surface (flat white), which is often overexposed. That is why one must rely on the photometric-generated data of the graph.



Graph of Hose Reflectance Coefficients.

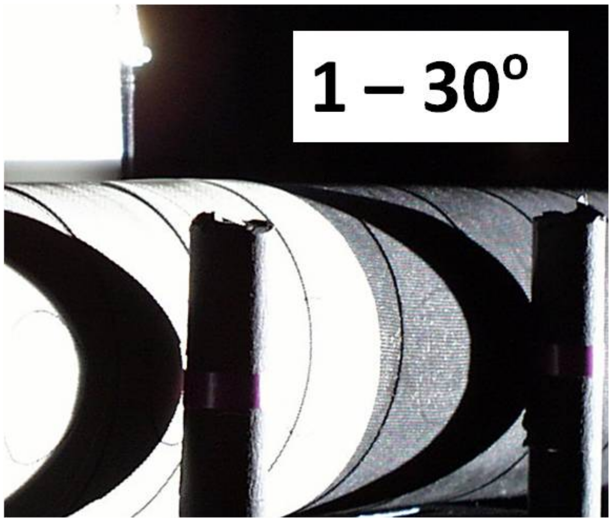


Photo of Hose 1 at 30 deg from surface.

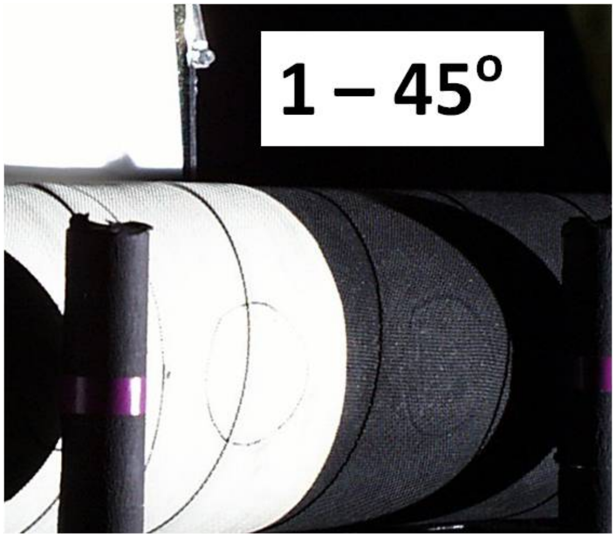


Photo of Hose 1 at 45 deg from surface.

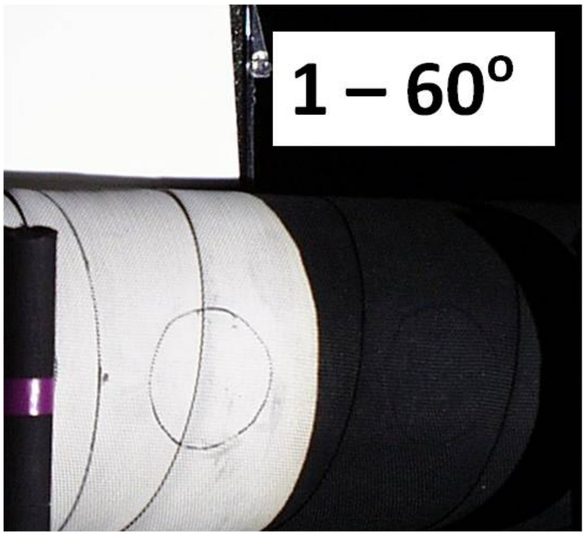
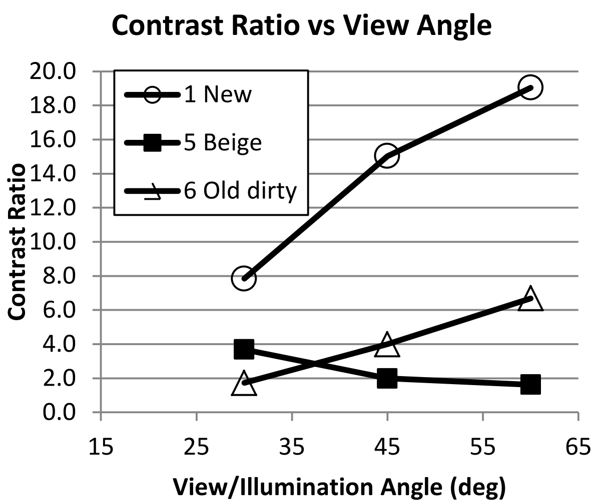


Photo of Hose 1 at 60 deg from surface.

Figure 29. Hose 1 (New Hose Sample) Graph and Photos



Graph of Hose Reflectance Coefficients.

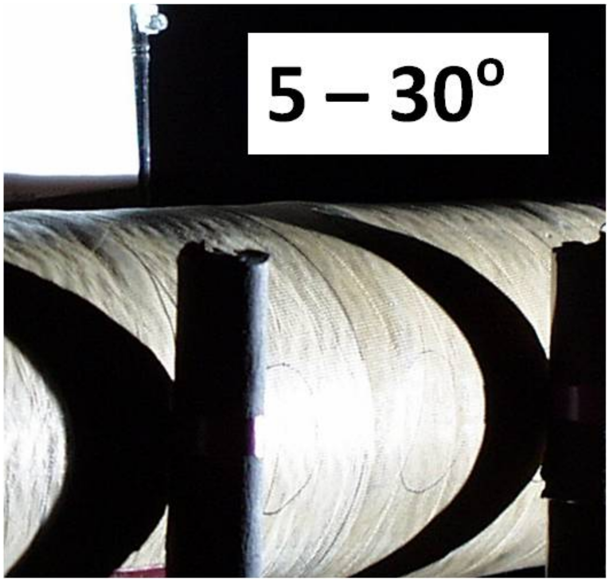


Photo of Hose 5 at 30 deg from surface.

Photo of Hose 5 at 45 deg from surface.

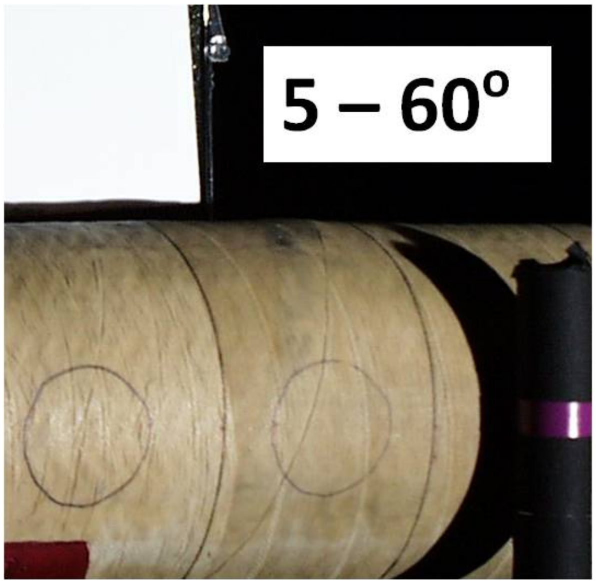
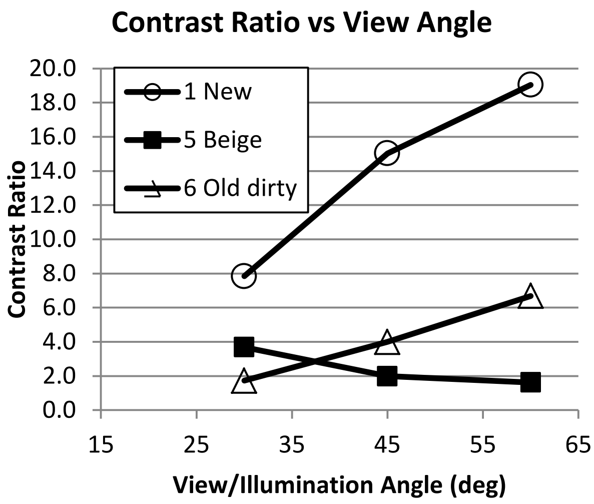


Photo of Hose 5 at 60 deg from surface.

Figure 30. Hose 5 (Old Beige Hose Sample) Graph and Photos



Graph of Hose Reflectance Coefficients.

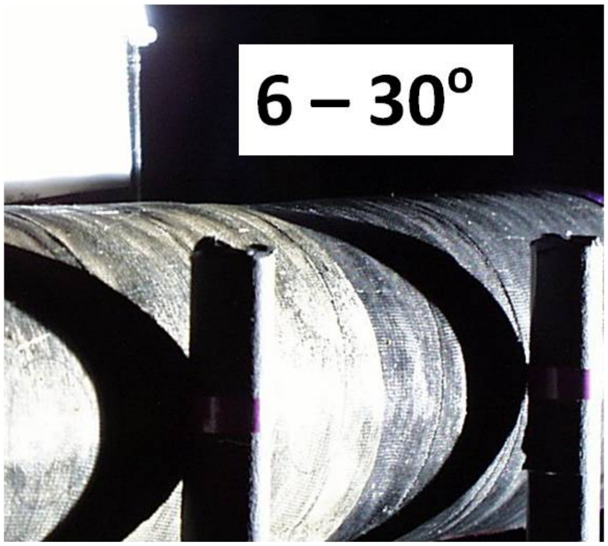


Photo of Hose 6 at 30 deg from surface.

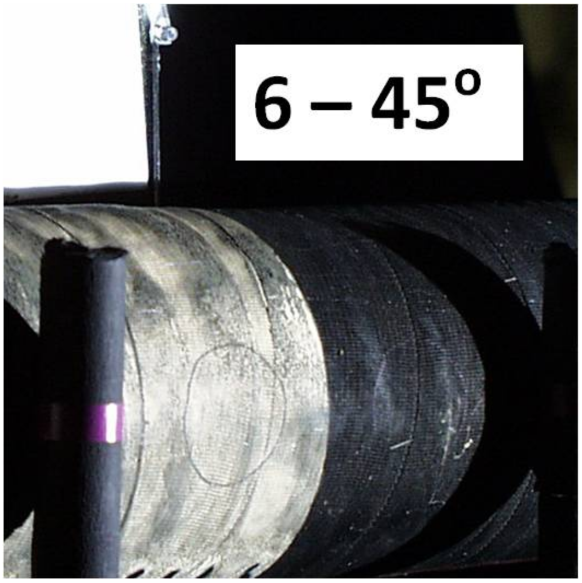


Photo of Hose 6 at 45 deg from surface.

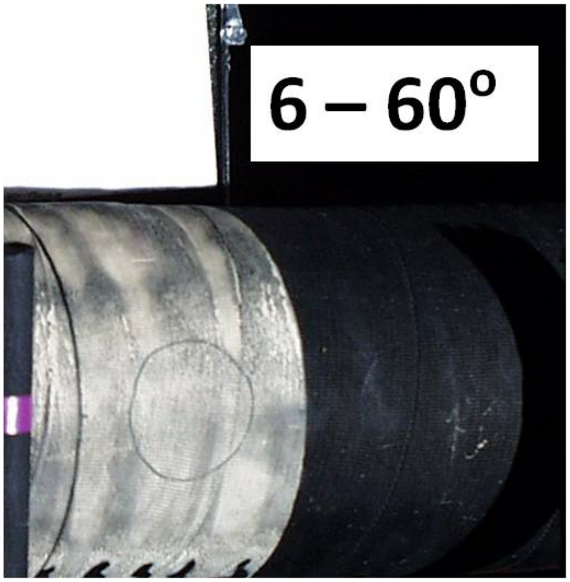


Photo of Hose 6 at 60 deg from surface.

Figure 31. Hose 6 (Old Dirty Hose) Graph and Photos

4 ANALYSIS AND DISCUSSION

Mil Standard 150A (1959) describes resolution charts of various contrast ranges that can be used to assess photographic lenses. The original document characterizes the contrast of these test charts in terms of optical density, which is beyond the scope of this report. Suffice to say that one can convert from optical density differences to contrast ratio and modulation contrast values. Table 10 lists the qualitative contrast levels assigned by Mil Std 150A (low, medium, and high contrast) along with the associated range of contrast ratio and modulation contrast levels (converted from the optical density difference values provided in the Mil Std).

Table 10. Contrast Level Definitions for Resolution Charts Extracted from Mil Std 150A (From Sections 5.1.1.7.1 through 5.1.1.3 of the Mil Std)

Contrast Level	C_r	C_m %
Low contrast	1.4	17
	1.6	23
	1.8	28
Medium contrast	5.6	70
	6.3	73
	7.1	75
High contrast	100.0	98

For the low and medium contrast levels a tolerance (plus/minus) range was specified around the value of the contrast, which is why there are 3 values associated for these contrast levels (the center value is the specified value and the upper and lower values define the allowed range). For the "high contrast" level the value specified is the minimum contrast valued needed in order to quality as "high contrast."

This information is provided as a reference to what has been considered low, medium, and high contrast in the past. Note that the best hose marking contrast (new hose sample #1), under the best viewing condition, achieved a contrast ratio of about 20 (Table 4), which would put it somewhere between "medium" and "high" contrast according to Table 10.

4.1 Lab Analysis of Hose Visibility

As expected, and as is apparent by looking at the picture of the hoses (Fig 9), the hose markings contrast ratios measured under non-specular reflection conditions correlate very well with the subjective judgment of contrast. The new hose (sample #1) had the highest contrast ratio followed closely by hose samples 3 and 4 (Table 4) for the non-specular contrast measurements made with the observation/measurement angle perpendicular to the surface and illumination at 45 degrees to either side. Similar results were also found for the second non-specular reflection measurement condition wherein the illumination source was perpendicular to the hose axis and the hose contrast was measured at 3 different angles with respect to the hose axis. The hose marking contrast for all hoses was fairly constant independent of viewing/measurement angle (Fig 15) indicating the hose and marking surfaces for all hoses have a fairly reasonable "Lambertian" (scatters light uniformly in all directions) aspect. This is good in that the contrast of the hose should remain reasonably constant independent of illumination direction(s) and viewing angle *with the notable exception of the specular reflection viewing geometry* discussed next.

If the illumination and viewing geometry is such that there is a significant amount of light in the specular reflection geometry (see Figure 16) then, according to the specular geometry contrast ratios results of Figure 20 the hose contrast ratios will decrease (less contrast) as one looks at the hose at angles closer to the hose axis. This indicates the hose and markings surfaces have a certain amount of "mirror-like" aspect to them as well as the Lambertian aspect. One might equate the overall effect to be somewhat equivalent to "semi-gloss" or "low sheen" paint, which looks fairly flat (no reflections) under most viewing conditions but does show some sheen or gloss if the specular viewing/illuminating geometry is involved. From Figure 20 it is apparent that five of the six hoses show contrast ratio decreases significantly as the angle of view is closer to the axis of the hose, which is in general what one would expect. The exception to this is old, beige hose sample #5, which was measured to have higher contrast as the view/measurement angle was closer to the hose axis. Figure 30 provides a summary of this result graphically along with photos of hose #5 at these different angles. Figures 21 and 22 show the reflection coefficients for the "white" and "black" part of the hoses respectively. From these figures it is apparent that hose #5 increases contrast as the view angle becomes smaller through a combination of the white reflectance coefficient increasing much more rapidly than the black reflectance coefficient (compared to the other hoses) resulting in the contrast ratio increasing with decreasing angle. However, in general, hose #5 has the worst contrast ratio of all of the hoses with the exception of the smallest angles in the specular viewing/measuring geometry. It might be beneficial to investigate the surface qualities of hose #5 more closely to see if one could achieve the effect of better contrast for smaller viewing angles (a desirable feature) but with higher overall contrast for all other conditions as well.

Figure 19, which is the overall contrast ratio results for the specular reflection geometry, is repeated here as Figure 32 to facilitate discussion. In addition to the somewhat unusual behavior of hose #5, a main "take-away" from this graph is that all the hoses have significantly low contrast ratios (actually, between "low" and "medium" contrast as defined in Table 10) at the 30 degree viewing/measurement angle with the exception of the clean, new hose #1. Although it was not practical to do so, if one had measured the contrast ratios for even smaller angles the trend of the graphs for all hoses (except number 5) indicate the contrast would be even worse yet. What makes this disconcerting is that the view the pilot has of the hose looking toward the tanker aircraft is probably less than the 30 degrees measured. The only good thing is that most likely the illumination source is not in the specular reflection geometry, which is what would cause the reduced contrast. One needs to make sure that artificial lighting used to illuminate the hose does not satisfy the specular reflection geometry for the pilot's view angle of the hose. Also, from an operational conditions standpoint, one would like to avoid natural illumination geometries in which the hose is illuminated by sunlight such that it is close to the specular reflection geometry (basically, flying toward the sun).

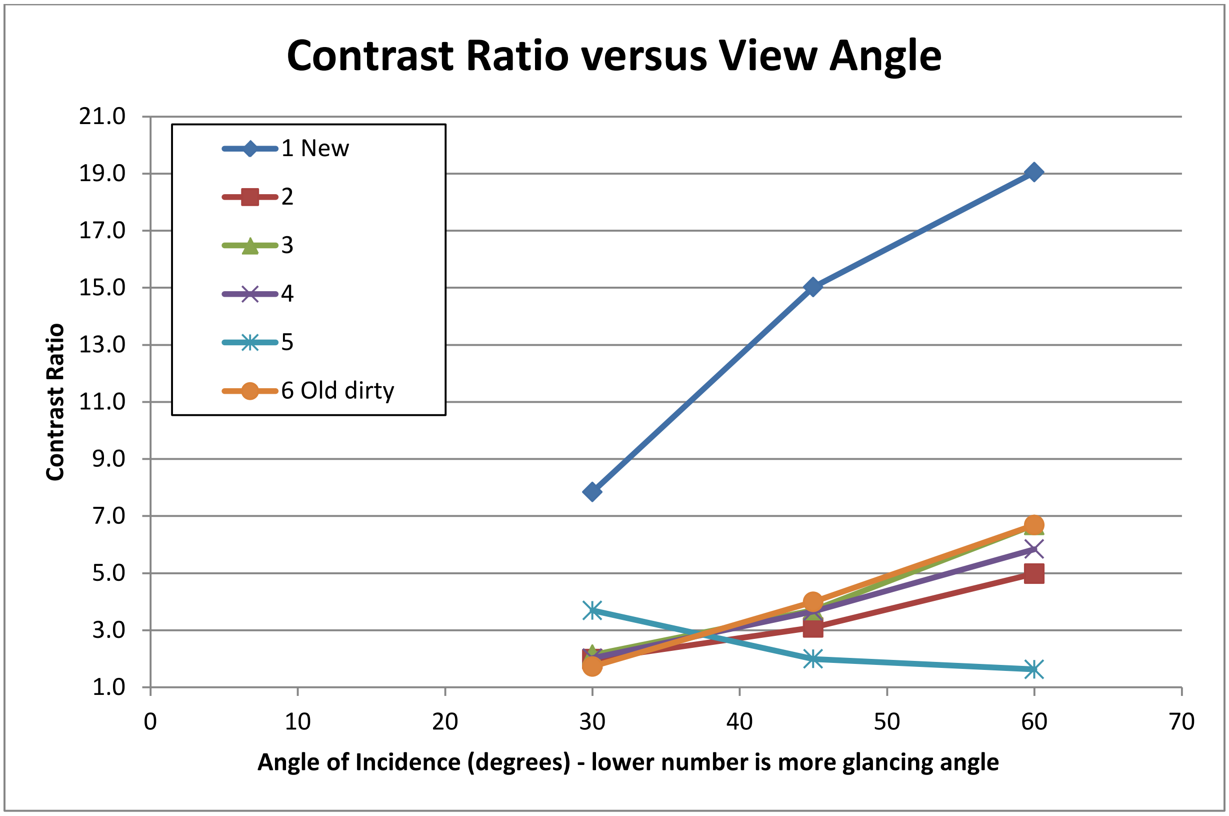


Figure 32. Summary Graph of Contrast Ratio as a Function of Viewing/Illuminating Angle for the Six Hose Samples Tested (Note: A Contrast Ratio of 1 Is the Lowest One Can Achieve - No Contrast)

Another main finding derived from Figure 32 is that under the specular reflection geometry we see a rather significant difference in contrast ratio between the new hose #1 and all of the other hoses whereas in the non-specular reflection viewing geometries hoses #3 and #4 measured (and appeared) to have almost as much contrast as hose #1. This is somewhat of a surprise in that one needs to measure/observe the hoses and markings under operationally relevant conditions (viewing angles, illumination angles, background luminances, viewing through windscreens, etc.) in order to come to valid conclusions concerning the visibility of the hose and markings.

The photographic results of Section 3.3.1 are fairly self-explanatory. As can be seen from the images the NVG and SWIR images produce results that appear to have contrasts similar to the contrasts seen in the visible spectrum photographs. The LWIR sensor images are sensitive to temperature differences and are drastically different than the other spectral bands (as one would expect) because the temperature differences between the hose and its markings under the lab illumination conditions were not very significant. If the hoses were imaged using LWIR under sunlight conditions then most likely there would be a higher contrast level as the black markings would absorb solar radiation more than the white part and would be hotter than the white part. However, for night viewing with no significant radiation source it is most likely that both the white and black parts of the hoses would be the same temperature and there would be no contrast in the LWIR images (worse than what the LWIR images show for the modest lab level illumination used in this evaluation).

4.2 Field Visibility of Hoses

Section 4.3 provides a summary of the main results of this laboratory evaluation of the refueling hose samples. However, these lab results need to be looked at with an eye toward actual field conditions under which these hoses are viewed by pilots, which was briefly alluded to in the previous section. The key parameters to extrapolating the results of this report to actual field viewing conditions include: the viewing geometry (from pilot's view), the illumination geometry/conditions (cloudy or not, sun angle, night illumination sources, background luminance), the hose main features (inherent contrast ratio of markings for the viewing conditions, size of markings), and the condition of the aircraft windscreen and HUD combiner glass (if applicable). It cannot be stressed enough that the quality of the windscreen and the sun angle on the windscreen can drastically reduce the observed contrast of even a "high contrast" new hose. This is a "system" level issue that includes operational practices (sun angle when refueling) as well as components of the "system" (e.g. the aircraft windscreen) that are not typically considered as part of the refueling scenario.

In the Introduction to this report, it was noted that the primary objective of this effort was to determine how well a pilot could see the markings on the refueling hose as opposed to determining the visibility of the hose itself (marked and/or unmarked sections) against a variety of background scenes. After reviewing draft versions of this report, the sponsoring agency has requested us to comment on the visibility of the hose itself as opposed to the markings, particularly for night refueling with the unaided eye. As presented in Section 2.1, contrast between an object of interest and its background is the primary parameter that determines the visibility of the object. Section 2.6 of this report briefly addresses the issue of human visual adaptation state and the effect it can have on the visibility of objects. A closely related parameter is perceived contrast, which may be different from measured contrast and can be caused by the interaction of eye adaptation state, object and background luminance levels, internal eye light scattering, and external veiling luminance effects such as those described in Section 2.8. A proper discussion of these effects is beyond the scope of this report. However, in general, it should be noted that objects viewed in a darkened environment (night refueling) will be more visible the "brighter" they are (higher luminance). Since hose luminance depends on both the level of illumination and the hose reflectance coefficient it should be apparent that the higher the reflectance coefficient the easier it should be to see that section of hose. Therefore, if one is viewing a white hose with black markings every ten feet or so it will be easier to see the white hose against the dark night background than it will be to see the black markings. Similarly, if one is viewing a black hose with white markings every ten feet or so it will be easier to see the white markings on the hose against the dark night background than the black hose. This is essentially the basis for the comment stated in Appendix F, namely: "If viewing the hose is important for these operations, then the white hose is a good choice."

However, there is another practical, operational element that needs to be considered with respect to used refueling hoses. If one looks at the reflectance coefficients listed in Table 2 for all hoses one notices that hoses described as black hoses with white markings have substantially lower reflectance coefficients of the white markings compared to the reflectance coefficients of the white hoses that have black markings. An inspection of the photograph in Figure 9 provides some insight into the reason for this. Although we have a very limited number of samples, it appears that with repeated use black hoses with white markings result in a substantial reduction in the reflectance coefficient of the white markings (e.g., hose #6) whereas the black markings on white hoses do not "rub off" onto the white hose (thereby presumably reducing the white hose reflectance coefficient) nearly as significantly. This would support the contention that, in general, a white hose with black markings should be more visible for night aerial refueling than a black hose with white markings.

5 CONCLUSIONS/RECOMMENDATIONS

Based on the results of this effort, it is apparent that the contrast between the refueling hose samples and the markings is dependent on the viewing and illumination angle geometry. Any evaluation of a possible new hose material needs to take this fact into account so that the evaluation conditions will provide results comparable to operational results.

Hose markings contrast can degrade significantly under specular reflection viewing/illumination geometry, which has implications for operational practices (don't fly toward the sun) and for determining when hoses need to be cleaned.

Refueling hose contrast observed in the field can be significantly different (worse) than contrast measured in the lab due to aircraft windscreen induced contrast loss mechanisms. These include windscreen haze caused by micro-scratches in the windscreen or windscreen materials that "glow" when illuminated by bright sunlight. Another contrast loss mechanism is reflection of the aircraft glare shield in the windscreen, the magnitude of which depends on the sun illumination angle, the amount of dust on the glare shield, and the reflection coefficient of the windscreen. These contrast loss mechanisms can vary significantly causing considerable loss of observed contrast during day-time refueling.

In general, a white hose with black markings should be more visible than a black hose with white markings.

We have insufficient data to make recommendations regarding hose cleaning requirements or minimum allowed hose contrast before cleaning/replacement is needed. In general, more contrast is better. One possible next step to determine the effectiveness of "hose cleaning" is to have hose samples 2, 3, 4, and 6 cleaned by folks who know how to clean hoses and then we could re-measure the contrast ratios of these hoses for comparison with their "uncleaned" state.

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Joint Helmet Mounted Cuing System (JHMCS) specification for minimum display contrast against 10,000 fl background.

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LIST OF FIGURES (APPENDIX)

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APPENDIX A - Aerial Refueling Hose Color and Markings Evaluation Criteria

Dex Kalt
14 Sept 2011

1. Requirement

Determine optimum aerial refueling hose markings and color on probe drogue automatic hose take-up type aerial refueling systems for use as a formation aid for receiver pilots. The hose markings should assist pilots in detecting hose movement and position while hooked up.

2. Supporting information

During the aerial refueling operation, the aerial refueling drogue, a hose stabilizing device, is the closest object in the receiver pilot's field of vision (prior to and after hook-up). This devise is approximately (with high-speed and fixed wing aircraft) two feet in diameter typically equipped with a 4" wide white cloth canopy which is attached to the outer struts. In many applications, white wide angle reflective tape is sewn into the canopy to enhance its visibility to pilots. In addition, several applications have drogue lights illuminating the drogue interior and/or LEDs to illuminate the exterior of the drogue attaching coupling.

A similar drogue which incorporates a white canopy over 52" in diameter with a 1 foot wide white cloth used for rotary wing helicopters aerial refueling. Night aided vision typically is used by the US services for night aerial refueling for rotary winged aircraft.

3. Criteria

The following criteria should be considered in determining and evaluating the subject requirements.

3.1 Acceptable minimum / maximum hose color to marking contrast range under a variety of lighting conditions. This should permit the pilots to detect hose movement and position from the tanker hose / drogue exit. This distance (pilot eye to drogue exit) may range from approximately 10 ' to 90 ' depending on the type of tanker drogue hose reel retracting / storage system.

3.2 Minimum / maximum hose marking bands' widths.

3.3 Hose drogue stowage exit light illuminating required for the associated factors of 3.1 and 3.2 above.

3.4 Access relationship of other primary receiver pilot tanker aircraft formation and position aids used in addition to the aircraft hose exit area.

3.5 Determine the need and hose markings spacing and size for receiver pilot to detect hose movement and rate of movement in relationship to the tanker i.e. 10 ' marking on current aircraft hoses.

3.6 Determine the need and spacing / size of hose position markings.

3.6.1 inner hose limit

3.6.2 outer hose limit

3.6.3 middle / sweet spot markings for holding tanker position (will vary with type aircraft and installation)

3.7 Need for in-service cleaning and maintenance and frequency for inspecting and insuring contrasting color markings range (as established in item 3.1 above) is maintained for pilot visibility throughout the hose life.

3.8 Investigate whether hose life is impacted by basic hose color, black/white or other.

3.9 Whether hose construction material selection for markings and endurance of these markings under repeated use in service applications, hose reel wrap, abrasion, etc. and cleanliness, maintenance etc.

4.0 Reference past test documents / reports of aerial refueling hoses.

APPENDIX B - Proposed Assessment of Refueling Hose Visibility

H.L. Task
30 Nov 2011

This proposal is based on a 22 Nov 2011 telecon that included ARSAG, Navair, and AFRL personnel and is in response to a request from ARSAG. The primary goal of these evaluations is to assess the visibility of the hose samples.

Samples: ARSAG will supply 3 or more hose samples (3-4 feet long) - white on black, black on white, and "dirty" white hose. Each sample will be clearly marked (new, old, dirty, etc.).

Measurements:

1) Spectral reflectivity: Two spectral reflectivity measurements will be done on each hose and each color segment (3 hoses times 2 colors each times 2 replications = 12 spectral reflectivity measurements. The replications will be on the same color/hose but in a different location. If the two measurements differ by too much (e.g. 5% of value) a third measurement will be made. Spectral range will include visible through NIR and SWIR, if possible (nominally 400nm - 2000nm). These measurements will be done perpendicular to the surface with broad spectrum illumination on the samples in a non-specular reflection geometry. A $BaSO_4$ Lambertian reflectance reference will be positioned next to each measurement location and will be measured as a reference. The spectral reflectivity for each location measured is the ratio of the sample measurement and the reference measurement.

2) Photometric reflectance: Although photometric reflectance (visible light) can and will be calculated from the spectral measurements above, this measurement will allow for a direct measurement of the photometric reflectance and serve as a cross-check. The same procedure as outlined above will be used except that the measurements will be made by a photometer. The photometric reflectance is the ratio of the luminance of the sample and the luminance of the $BaSO_4$ reference.

3) Specular (mirror-like) effects: It is assumed that both the white and black parts of the hoses are essentially flat; which means they reflect light uniformly in all directions independent of the directionality of the light source or the observer. The purpose of this measurement is to check that assumption. A photometer will be used to measure the luminance of the sample and the luminance of an adjacent $BaSO_4$ reference. However, the illumination in this case will be a light source positioned in a reflection geometry and two measurements will be made for each hose location measured. The light source (e.g. photo flood light) will be positioned to illuminate the hose at approximately a 30 degree angle from horizontal. The luminance of the hose and the reference will be made with the photometer perpendicular to the hose/reference and then at a 30 degree angle with respect to horizontal on the opposite side from the light source. The reflectance of the hose will be calculated for each of the viewing geometries to determine if there is a significant difference between them.

4) Photographic documentation: In order to provide documentation of the measurements and for a visual cross-check the samples will be photographed using three different spectral band sensors: visible, near IR, and short-wave IR. These images will be captured for each of the samples set up for both the geometries described in 2) and 3) above. Other photographs may be produced as appropriate.

Analysis:

1) The spectral reflectivity measurements of 1) above will be used to calculate the reflectivity of each point measured for each of the 3 spectral bands of interest: visible, NIR, SWIR.

2) The visible spectral reflectivity values obtained above will be compared to the photometric (visible light) reflectivity measured in 2) above.

3) A theoretical discussion of hose visibility will be provided with the calculated contrast of the black and white hose markings and possible backgrounds. Also, the theoretical (and real) effects of contrast loss due to aircraft windscreens and HUD combiners will be addressed and analyzed in the context of the hose reflectivity measurements.

Deliverables: A final report on the results obtained in this evaluation will be provided along with whatever recommendations are appropriate based on the results.

APPENDIX C - Test Plan: Assessment of Refueling Hose Visibility

H.L. Task

3 April 2012 - updated 6-23-2012

Samples: ARSAG will supply five - six hose samples (3-4 feet long) - white on black, black on white, and "dirty" white hose. Each sample will be clearly marked with a tag attached to one end of the sample hose section. The tag will include the type of hose and its basic characteristics (new, old, dirty, white on black, black on white, etc.). Additionally, samples will be clearly labeled with a number (1 through N where N is 6 or less) and a photograph will be taken of each numbered hose section sample with a clearly readable placard that includes the sample number in large numbers.

1) Spectral reflectivity

Measurement: Two spectral reflectivity measurements will be done on each hose and each color segment (e.g. 3 hoses times 2 colors each times 2 replications = 12 spectral reflectivity measurements). The replications will be on the same color/hose but in a different location. If the two measurements differ by too much (e.g. 5% of value) a third measurement will be made. Spectral range will include visible (nominally 400nm to 700nm) through NIR (680nm to 950nm) and SWIR (950nm to 1300nm, and, to the extent possible, LWIR). These measurements will be done perpendicular to the surface with broad spectrum (incandescent) illumination on the samples in a non-specular reflection geometry. A $BaSO_4$ Lambertian reflectance reference will be positioned at each measurement location and will be measured as a reference. The spectral reflectivity for each location measured is the ratio of the sample measurement and the reference measurement as a function of wavelength. The pictures below show the geometry for making the spectral radiometric scans.

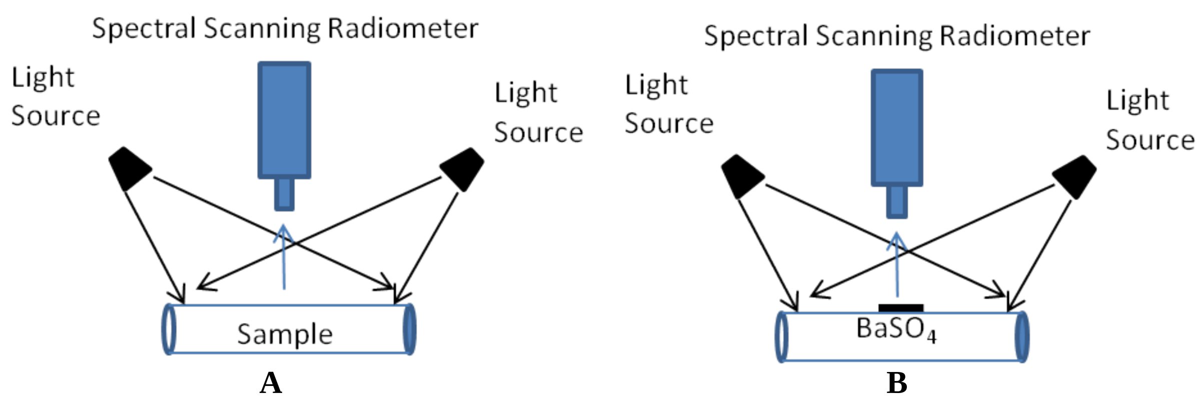

Figure 33. Spectral Scanning Radiometer Geometry: A (Hose Sample) and B (Reference)

The light sources shown in Figure C-1 are incandescent and provide a broad spectrum of illumination. The light sources will be several feet away from the sample and should provide the vast majority of the light that is illuminating the sample (room lights MAY need to be turned off). Without changing anything, after the sample has been scanned the $BaSO_4$ reference will be placed on top of the area of hose sample that was measured and a reference scan will be made.

The area of the sample hose that will be measured will be relatively small - on the order of 1-2 centimeters in diameter. The table below summarizes the various spectral curves that will be measured/calculated. If Data-Takes A and B are more than 5% different in values then Data-Take C will be accomplished. Each Data-Take is at a different location on the hose.

Table 11. Spectral Scans Accomplished With the Spectral Scanning Radiometer

Note: the contents of each cell correspond to the Sample number (1-6), the scan type (Sample or BaSO4), the "color" (Black or White), and the data-take session (A, B, or C). Each cell also corresponds to a spectral curve that graphs spectral radiance as a function of wavelength.

			Sample number (1 – 6)				
		Spectral curves	**1**	**2**	**3**	**4**	**5**
Data take A	Black (B)	A. Sample scan	1SB-A	2SB-A	3SB-A	4SB-A	5SB-A
		B. $BaSO_4$ scan	1BB-A	2BB-A	3BB-A	4BB-A	5BB-A
		Calculate ratio A/B	1RatioB-A	2RatioB-A	3RatioB-A	4RatioB-A	5RatioB-A
	White (W)	A. Sample scan	1SW-A	2SW-A	3SW-A	4SW-A	5SW-A
		B. $BaSO_4$ scan	1BW-A	2BW-A	3BW-A	4BW-A	5BW-A
		Calculate ratio A/B	1RatioW-A	2RatioW-A	3RatioW-A	4RatioW-A	5RatioW-A
Data take B	Black (B)	A. Sample scan	1SB-B	2SB-B	3SB-B	4SB-B	5SB-B
		B. $BaSO_4$ scan	1BB-B	2BB-B	3BB-B	4BB-B	5BB-B
		Calculate ratio A/B	1RatioB-B	2RatioB-B	3RatioB-B	4RatioB-B	5RatioB-B
	White (W)	A. Sample scan	1SW-B	2SW-B	3SW-B	4SW-B	5SW-B
		B. $BaSO_4$ scan	1BW-B	2BW-B	3BW-B	4BW-B	5BW-B
		Calculate ratio A/B	1RatioW-B	2RatioW-B	3RatioW-B	4RatioW-B	5RatioW-B
Data take C (optional)	Black (B)	A. Sample scan	1SB-C	2SB-C	3SB-C	4SB-C	5SB-C
		B. $BaSO_4$ scan	1BB-C	2BB-C	3BB-C	4BB-C	5BB-C
		Calculate ratio A/B	1RatioB-C	2RatioB-C	3RatioB-C	4RatioB-C	5RatioB-C
	White (W)	A. Sample scan	1SW-C	2SW-C	3SW-C	4SW-C	5SW-C
		B. $BaSO_4$ scan	1BW-C	2BW-C	3BW-C	4BW-C	5BW-C
		Calculate ratio A/B	1RatioW-C	2RatioW-C	3RatioW-C	4RatioW-C	5RatioW-C

Analysis/Results: The data collected in Table C-1 will be used to calculate the contrast ratios for each hose sample, spectral range and Data-Take as outlined in Table C-2 below:

Table 12. Contrast Ratios for the Different Spectral Ranges and Hose Samples

Note: each Contrast Ratio cell will contain a number greater than one since the contrast ratio is defined as the higher radiance divided by the lower radiance. The other cells will contain a number less than one, which is the fraction of light that is reflected from the sample.

			Sample number				
Spectral Range			1	2	3	4	5
Data Take A	Visible	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Near IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Short Wave IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
Data Take B	Visible	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Near IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					
	Short Wave IR	Black Reflectance					
		White Reflectance					
		Contrast Ratio					

2) Photometric reflectance

Measurement: Although photometric reflectance (visible light) can and will be calculated from the spectral measurements above, this measurement will allow for a direct measurement of the photometric (visible) reflectance and serve as a cross-check. The same procedure as outlined above will be used except that the measurements will be made by a photometer. The photometric reflectance is the ratio of the luminance of the sample and the luminance of the $BaSO_4$ reference.

Table 13. Photometric Measurements of Hose Reflectance and Contrast Ratios

		Sample Number 1	2	3	4	5
Data Take A	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
Data Take B	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
Data Take C	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					

Analysis/Results: Table C-3 contains both the raw data values and the calculated reflectance and contrast ratio values. These can be compared with the values obtained using the spectral scanning radiometer.

NOTE: Procedurally, it will probably be most efficient and accurate if the spectral scanning radiometric measurements and the hand-held photometer measurements are done at essentially the same time. The procedure would be to set up the light sources, hose sample, and radiometer as depicted in Figure C-1. After making the spectral scan of the sample, a hand-held photometer would be held near the spectral scanning radiometer (without disturbing the hose sample, radiometer, or light sources) and a photometric reading would be obtained. After the photometric reading is obtained the BaSO4 reference is placed on the sample over the area of the hose that was measured and another radiometric and photometric measurement of the BaSO4 reference would be made. Most likely, it will be easier to move the hose to the next location to be measured. The black areas and the white areas could be measured in any order but the SPECIFIC area measured needs to be marked in some way to make sure one could get back to the same area - perhaps by using masking tape to OUTLINE the areas measured. As indicated above, 2 or 3 white areas and 2-3 black areas will be measured on each hose sample.

3) Specular (mirror-like) effects: It is assumed that both the white and black parts of the hoses are essentially flat (matte finish); which means they reflect light uniformly in all directions independent of the directionality of the light source or the observer. The purpose of this measurement is to check that assumption. A photometer will be used to measure the luminance of the sample and the luminance of a $BaSO_4$ reference. However, the illumination in this case will be a light source positioned in a reflection geometry (see Figure C-2, A and B). Two measurements will be made for each hose location measured: one of the hose and one of the BaSO4 reference. The light source (e.g., photo flood light) will be positioned to illuminate the hose at various angles from horizontal (60, 45, 30 and, if possible, 15 degrees). The reflectance of the hose will be calculated for each of the viewing geometries to determine if there is a significant difference between them. Since this is a specular reflectance test only two parts of each hose sample needs to be measured: a black area and a white area.

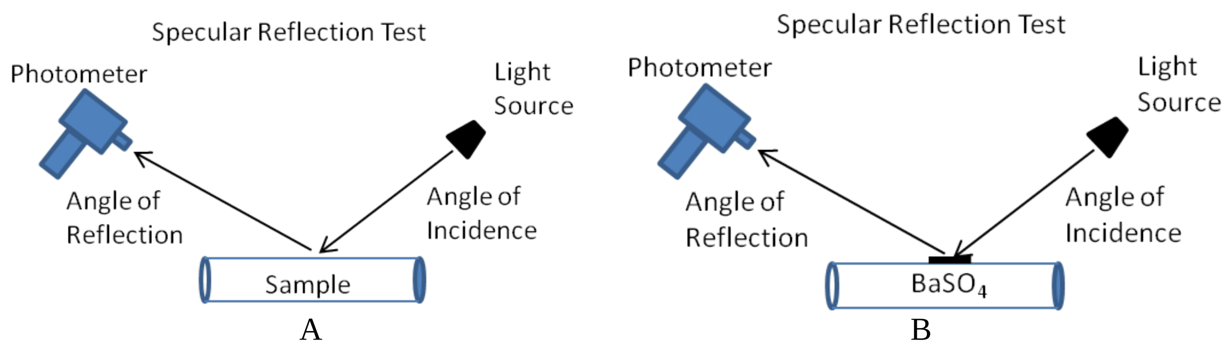

Figure 34. Equipment Set-Up to Measure Specular Reflectance

NOTE: Procedurally, it may be advantageous to use a laser pointer and an optical protractor to set the angle of incidence and the angle of reflection. The optical protractor would be placed at the part of the hose sample to be measured and the laser pointer would be adjusted such that the angle it arrives at the sample is one of the angles to be measured. The illuminating source, which should be located fairly far away from the sample so as to provide approximately parallel light illuminating the sample, would then be place in the location of the laser pointer. The same method could be used to establish the position of the small photometer, which could be tripod-mounted. Also, note that angles are measured from horizontal, not vertical. Previous measurements (1 and 2 above) were made at a 90 degree angle from horizontal.

Table 14. Measurement of Reflectance and Contrast Ratios for Specular Lighting Conditions

Angle		Sample Number 1	2	3	4	5
60 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
45 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					
30 degrees	Black Luminance					
	BaSO4 Luminance					
	Black Reflectance					
	White Luminance					
	BaSO4 Luminance					
	White Reflectance					
	Contrast Ratio					

4) Photographic documentation: In order to provide documentation of the measurements and for a visual cross-check the samples will be photographed using three different spectral band sensors: visible, near IR, and short-wave IR. These images will be captured for each of the samples set up for both the geometries described in 2) and 3) above. Other photographs may be produced as appropriate including photographs to fully document the procedures and geometry suitable for the final report.

APPENDIX D - Night Aerial Refueling Article from Rotovue

Extracted from:
http://www.camplejeuneglobe.com/rotovue/news/around_the_corps/article_3be9f1a6-a415-11e1-84be-001a4bcf887a.html

VMM-162 refuels under cover of darkness

Story and photos by Lance Cpl. Kyle N. Runnels

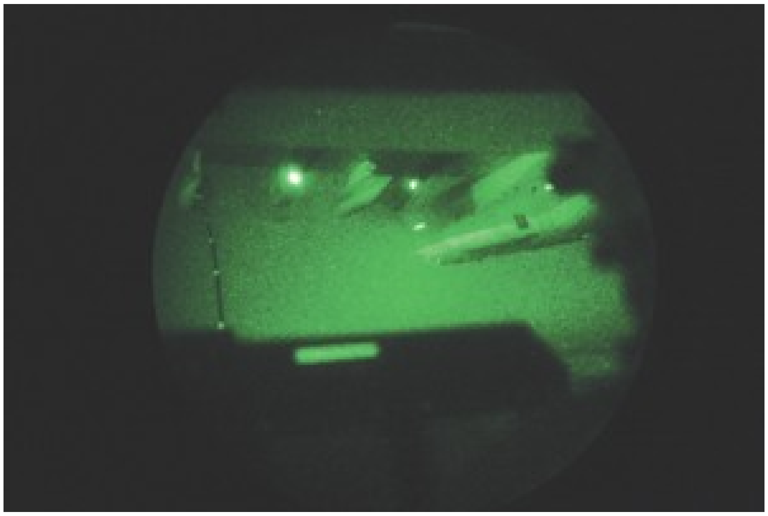

Figure 35. Marine Medium Tiltrotor Squadron 162 Conducting a Nighttime Aerial Refueling Training

Aerial refueling is a difficult task to master and requires extensive training for pilots. As part of their ongoing proficiency, Marines from Marine Medium Tiltrotor Squadron 162 conducted nighttime aerial refueling training, May 10.

"Aerial refueling is an absolute force multiplier," said Capt. Kyle G. Stuart, VMM-162 MV-22B Osprey pilot. "One of our greatest limitations, shared by aircraft of all types, is fuel. When planned for and properly coordinated, aerial refueling allows us to take off from anywhere, with a full passenger or cargo load, light on fuel, and then receive fuel from a KC-130J Hercules, extending our reach and mission capability."

Conducting aerial refueling can be a hard task to master during the day, but doing it in the dark adds a whole new dynamic.

"Our field of view at night through goggles is reduced to 40 percent of that during the day," said Stuart. "The greatest difficulty is a loss of depth perception and the ability to judge the rate of closure when using night vision devices."

Refueling at night is an important ability to keep proficient. Many operations in Afghanistan are done at night to provide a cover of darkness.

“Night training is important because in combat, most of the flying is done at night,” said Cpl. Jeremy F. Provost, VMM-162 Osprey crew chief. “Flying at night is safer because the enemy can’t track the aircraft as easily. Night flying is also difficult and hazardous, so it is important for the aircrew to train at night so they may be more proficient. We train like we fight.”

The crew flew off the coast of Topsail Island where they met with a KC-130J from Marine Aerial Refueler Transport Squadron 252 out of Marine Corps Air Station Cherry Point.

At 9,000 feet, the MV-22B pilots carefully flew the Osprey up to the suspended aerial refueling hose, a long refueling line with a basket hanging down from the tanker. The pilots had to carefully guide the Osprey’s refueling probe into the basket of the refueling hose.

“The main difficultly of aerial refueling is perceived pressure,” said Stuart. “Basically, the pilot puts more pressure on himself or herself because of the additional anxiety of operating so close to another aircraft. The key piece of advice given to new students of aerial refueling is to not stare at the basket. Small, deliberate, smooth control, power and stick inputs are also important.”

After successfully refueling, the Marines returned to New River a little more proficient at their job than when they took off earlier that day.

“Once a pilot is trained to safely execute aerial refueling it becomes an extremely safe and viable option to reduce flight planning requirements and possible limitations associated with fuel needs,” said Stuart.

APPENDIX E - Visibility of Refueling Hose Red Stripe for Both Visible and Night Vision Goggle Viewing Conditions Summary Report

H. L. Task

5/23/05

A section of aircraft refueling hose with a red stripe applied to it was measured to determine the visibility of the red stripe against the black hose background for both direct vision and night vision goggle (NVG) viewing. The spectral reflectivity of the black hose and the red stripe was measured using a spectral scanning radiometer (model IS320) and a white, perfect diffuse reflector reference source (barium sulfate – BaSO4). The hose/stripe was illuminated with an incandescent light source and the spectral distribution reflected from the hose and from the stripe was measured. The BaSO4 reference surface was then placed at the same location as the hose/stripe and the reference spectral distribution was measured. By dividing the hose/stripe spectral distributions by the reference distribution one can obtain the spectral reflectivity of the two surfaces being tested (the hose and the red stripe – see figure below).

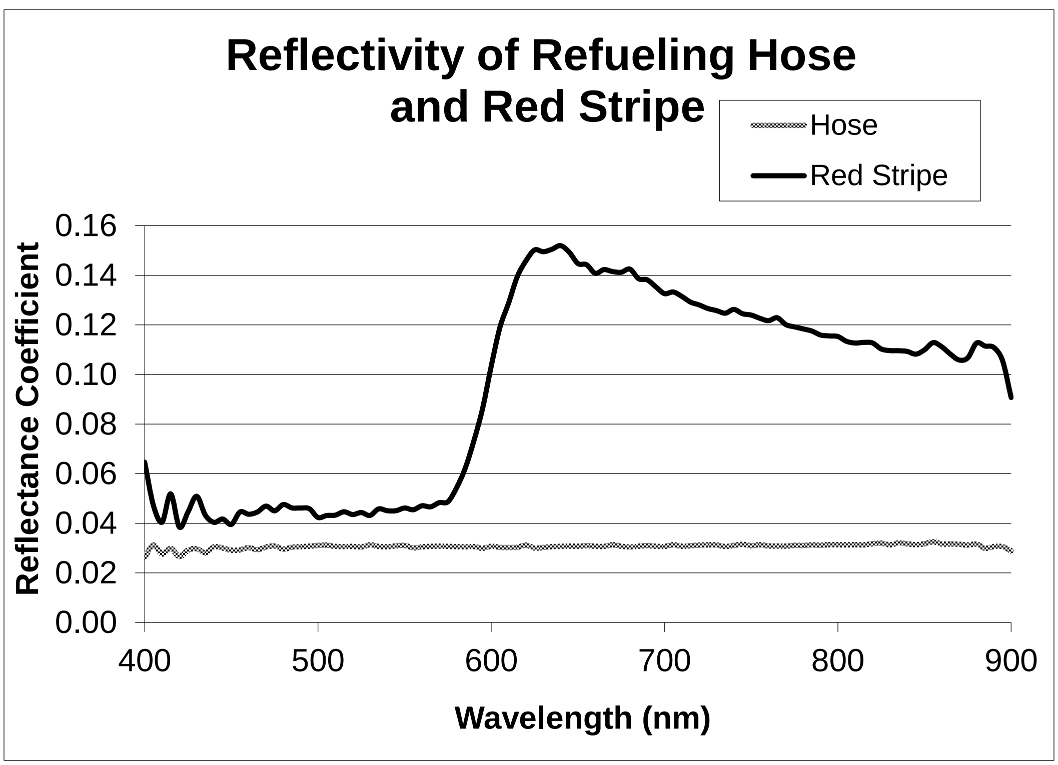

Figure 36. Spectral Reflectivity of Black Refueling Hose and Red Stripe for a 45-Degree Illumination Angle

Using the data from Figure E-1 it is possible to calculate the integrated relative reflectance for both the black hose and the red stripe weighted for the visual photopic curve, NVG Class A, NVG Class B, and NVG Class C curves. Using these integrated relative reflectance values it is then possible to calculate the modulation contrast of the red stripe against the black hose as viewed with direction vision or through any of the NVGs noted above. The table below is a summary of the modulation contrast of the red stripe against the black hose for each of the viewing conditions noted.

Table 15. Summary of Modulation Contrast of the Red Stripe against the Black Hose for Vision and through Night Vision Goggles

	Visible	NVIS A	NVIS B	Leaky Grn (C)
Percent Contrast	**36.3**	**30.3**	**29.5**	**29.4**

As can be seen from Table E-1 the visible contrast is somewhat higher than the various NVG viewing contrasts (36 percent versus about 30 percent). However, all values would be considered a medium level of contrast and should be readily visible to the viewer.

APPENDIX F - The Visibility of White Refueling Hose with Red Stripe to the Human Eye and to Night-Vision Goggles

Peter L. Marasco, PhD
Sharon A. Dixon

Air Force Research Laboratory
Human Effectiveness Directorate
AFRL/HECV

30 August 2005

At the request of the University of Dayton Research Institute, the Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Interface Division, Battlespace Visualization Branch (AFRL/HECV) examined a section of white refueling hose. Spectral measurements of the hoses' reflectivity were made and analyzed for visibility to the human eye and through night-vision goggles (NVGs). This report documents AFRL/HECV's findings.

The spectral reflectivity of the white hose and the red stripe were measured using a spectral scanning radiometer. These measurements were compared to a white, perfect diffuse reflector reference source (barium sulfate – $BaSO_4$). To make these measurements, the hose and stripe were first illuminated with a blackbody, incandescent light source. The spectral distributions reflected from the hose and from the stripe were then measured. The $BaSO_4$ reference surface was then placed at the same location as the hose/stripe and its spectral distribution was measured as a uniform white reference. The spectral reflectivity was then calculated by dividing the hose and stripe spectral distributions by the reference distribution (see figures below).

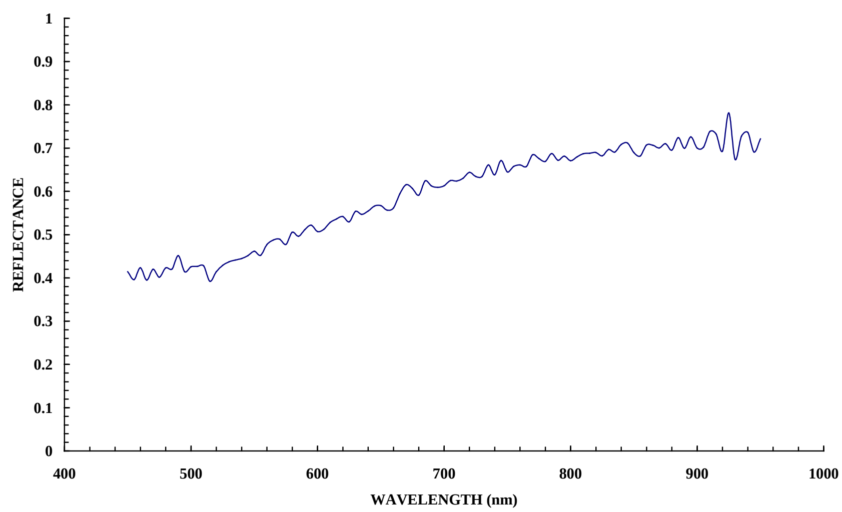

Figure 37. Spectral Reflectivity of White Refueling Hose at Wavelengths to Which the Human Eye and Night-Vision Goggles are Sensitive

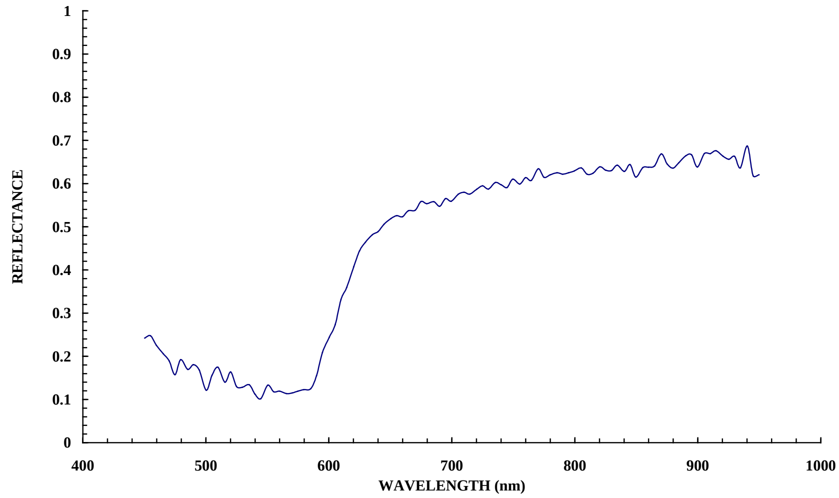

Figure 38. Spectral Reflectivity of the Red Stripe Found on White Refueling Hose at Wavelengths to Which the Human Eye and Night-Vision Goggles are Sensitive

Using the data in Figures F-1 and F-2, it is possible to calculate the integrated relative reflectance for both the hose and the red stripe weighted for the human visual response, the Class A, Class B, and Class C night-vision imaging system (NVIS) spectral response. These data can then be used to calculate the contrast of the red stripe against the white hose as viewed by an observer with their unaided eye or through any of the NVGs noted above. These calculated hose characteristics are listed in the table below.

Table 16. Reflectance of the White and Red Parts of the Refueling Hose and the Calculated Contrasts of the Red Stripe against the White Hose for Four Spectral Bands

	Visible	**NVIS A**	**NVIS B**	**NVIS C**
Reflectance – Red	31%	60%	62%	56%
Reflectance – White	56%	71%	73%	70%
Red/White Contrast	29%	8.4%	8.1%	11%

One can see from Table F-1 that for visible light, the red stripe has sufficient visible contrast to make it relatively easy to see under most illumination conditions (29%). However, it would be difficult to see under low illumination conditions. This is not the case in the infrared. Both red and white parts of the hose reflect strongly in the infrared and should appear fairly “white” through an NVG. Therefore, the stripe will be difficult to see when viewed through an NVG since its reflectivity in the various NVIS regions is very similar to the reflectivity of the white hose.

One should also note that the hose reflects rather strongly in the infrared, and, if properly illuminated, will be very prominent during refueling operations. If viewing the hose is important for these operations, than the white hose is a good choice. However, if the visibility of the hose is not operationally important, visibility of the white hose might not be necessary or desirable. One should consider another color for the hose to reduce its visibility.

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AFRL	Air Force Research Laboratory
ARSAG	Aerial Refueling Systems Advisory Group
$BaSO_4$	Barium Sulfate
BRDF	Bidirectional (azimuth and elevation) Reflectance Distribution Function
HUD	Head-Up Display
JHMCS	Joint Helmet Mounted Cuing System
LED	Light-Emitting Diode
LWIR	Long-Wave Infra-Red
Navair	U.S. Navy Naval Air Systems Command
NVG	Night Vision Goggles
SWIR	Short-Wave Infra-Red

DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433-7008

10 September 2013

MEMORANDUM FOR DTIC-OQ
ATTN: INFOSEC
8725 JOHN J. KINGMAN ROAD
FORT BELVOIR, VA 22060-6218

FROM: 711 HPW/OMCA (STINFO)
2947 Fifth Street
Wright-Patterson AFB, OH 45433-7913

SUBJECT: Request to Change the Distribution Statement on a Technical Report

This memo documents the requirement for DTIC to change the distribution statement on the following technical report from distribution statement D to A. Approved for Public Release; distribution is unlimited.

AD Number: ADB387179
Publication number: AFRL-RH-WP-TR-2012-0145
Title: Assessment of Refueling Hose Visibility

Reason for request: The report was downgraded from D to A so that the information conveyed within the report would reach a farther audience within the aerial refueling community. The findings from this assessment will be incorporated into the ARSAG international standard which is utilized worldwide by both civilian and commercial aircraft platforms, and provides critical safety guidance for optimizing refueling hose markings to enhance visibility, efficiency and safety.

Donald Denio

DONALD DENIO
STINFO Officer
711th Human Performance Wing